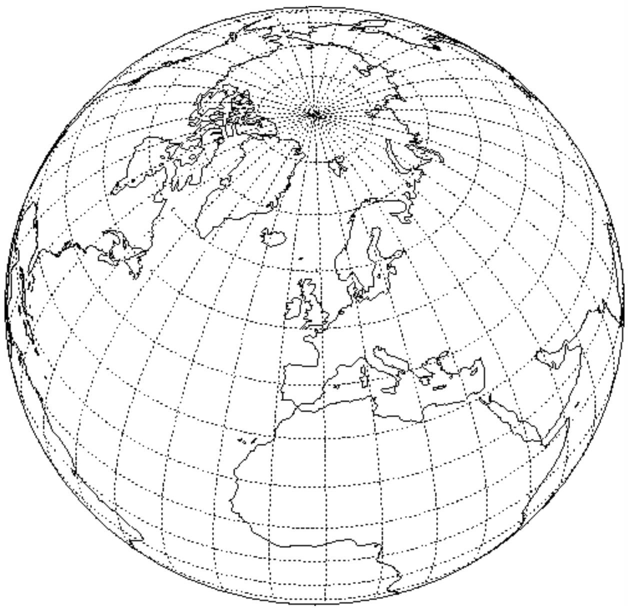
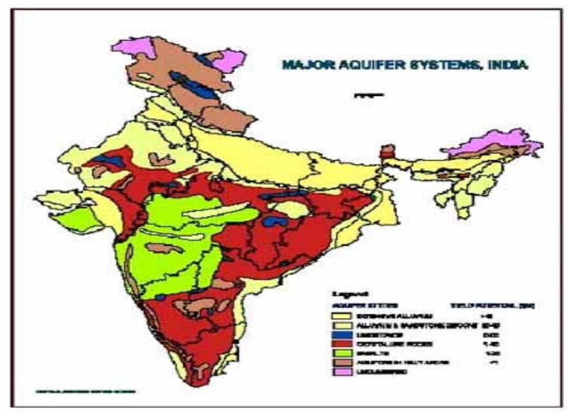
GROUNDWATER QUALITY SERIES:
GWQS/ 10/2007-2008

# STATUS OF GROUNDWATER QUALITY IN INDIA -Part-II






**CENTRAL POLLUTION CONTROL BOARD**
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**April, 2008**

GROUNDWATER QUALITY SERIES:
GWQS/ 10/2007-2008

# STATUS OF GROUNDWATER QUALITY IN INDIA Part - II

CPCB


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अध्यक्ष
**J. M. MAUSKAR**, IAS
Chairman

## *FOREWORD*

In recent years, the increasing threat to groundwater quality due to human activities has become a matter of great concern. Most of the groundwater quality problems are caused by contamination and by over-exploitation, or by combination of both. Rapid urbanization and industrialization in India have resulted in steep increase in generation of wastes. Due to lack of adequate infrastructure and resources, the waste is not properly collected, treated and disposed; leading to accumulation and infiltration causing groundwater contamination. The problem is more severe in and around large cities as also various clusters of industries.

Ground water is required for domestic, irrigation and industrial uses. In India, a large part of drinking water supply is fulfilled by ground water, thereby increasing its vital importance. In many of the areas groundwater is only source of drinking water, thus a large population is exposed to risk of consuming contaminated water. There are spatial and temporal variations in the quality of ground water and this is primarily governed by the extent and composition of dissolved solids present.

In this background, Central Pollution Control Board with the help of National Institute of Hydrology (NIH), Pollution Control Research Institute (PCRI) of Bharat Heavy Electrical Ltd. (BHEL) and the Pollution Control Cell, Thane Municipal Corporation, Thane has initiated a detailed survey of groundwater quality in Metropolitan cities (Cities having population > 1 million+) of the country. In order to achieve the objectives of the Study, ground water samples from the Metropolitan Cities of Andhra Pradesh: Hyderabad, Vishakhapatnam; Cities of Bihar: Patna; Cities of Delhi state: Delhi; Cities of Gujarat: Ahmedabad, Rajkot, Surat, Vadodara; Cities of Haryana: Faridabad; Cities of Jharkhand: Dhanbad, Jamshedpur; Cities of Karnataka: Bangalore; Cities of Kerela: Kochi; Cities of Madhya Pradesh: Bhopal, Indore, Jabalpur; Cities of Maharashtra: Nagpur, Nasik, Pune, Mumbai; Cities of Punjab: Amritsar; Cities of Rajasthan: Jaipur; Cities of Uttar Pradesh: Allahabad, Varanasi, Kanpur; Cities of West Bengal: Kolkata, Asansol; and were collected during pre- and post-monsoon seasons during 2004-2005 and 2006-2007were analysed for various water quality parameters.

The part – I of Status of Groundwater Quality in India which was published in February 2007 included eight major metropolitan cities of the country. The results of this survey with respect to all the 27 metropolitan cities are summarized in this Report, which presents the environmental profiles of metropolitan cities and their groundwater quality status. The groundwater quality data obtained during Survey were evaluated against drinking water quality [BIS 10500, (1991) & WHO (1996) Standards] and irrigation water quality requirements. Salinity, Nitrate, Coliform & Fluoride are the main water quality issues in majority of the metro cities of the country. Considering the competing demand on this scarce resource, the report highlights the need for judicious use of groundwater and also lists out remedial measures.

I hope the Report will be use to the planners, decision makers, scientists and engineers concerned with the management and protection of ground water quality in the country, especially in the metropolitan cities.

02nd May, 2008

(J. M. Mauskar)

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## CONTRIBUTIONS

| | |
|---|---|
| **Guidance, Planning, and Principal Coordinators** | **Dr. B. Sengupta, Member Secretary**<br>**Dr. R. C. Trivedi, Additional Director** |
| **Project Coordination, Report Compilation & Preparation** | **Dr. Sanjeev Agrawal, Scientist `C'**<br>**Ms. Pramila Gupta; JRF**<br>**PAMS Division, CPCB, Delhi.** |
| **Monitoring & Analysis of Groundwater Samples in Metropolitan Cities** | **I) National Institute of Hydrology, Roorkee**<br>**II) Pollution Control Research Institute (PCRI, BHEL), Haridwar, Uttarakhand.**<br>**III) Pollution Control Cell, Thane Munucipal Corporation (TMC), Thane.** |

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1. The ground water quality of the 14 Metropolitan Cities of Faridabad, Delhi, Jaipur, Bhopal, Indore, Jabalpur, Nagpur, Nasik, Pune, Bangalore, Hyderabad, Vishakhapatnam, Patna and Kochi has been assessed to see the suitability of ground water for domestic and irrigation applications.
2. Twenty five ground water samples were collected each during pre- and post-monsoon seasons in the year 2004 and analysed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and polynuclear aromatic hydrocarbons.
3. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified.
4. The quality of the ground water varies from place to place with the depth of water table.
5. The bacteriological analysis of the samples indicates some sign of bacterial contamination at few locations. Inadequate maintenance of hand pump, improper sanitation and unhygienic conditions around the structure may be responsible for bacterial contamination at these locations.
6. Pesticide analysis indicated the presence of some chlorinated pesticides at certain locations but their content was well within the permissible limits for drinking water at most of the locations. No organo-phosphorous pesticides and polynuclear aromatic hydrocarbons were detected in any of the ground water samples of the metropolitan cities.
7. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content.
8. An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram, Durov's plot, U.S. Salinity Laboratory and Gupta's classification.
9. The results of the study have been presented in tabular as well as graphical forms. Percentage distribution of samples for various water quality parameters in ground water of metropolitan cities have been summarized in the tables.

10. The ground water quality of the 10 Metropolitan Cities (2006-2007) of Ahmedabad, Rajkot, Surat, Vadodara, Asansol, Dhanbad, Jamshedpur, Kolkata, Amritsar and Kanpur has been assessed to see the suitability of ground water for domestic and irrigation applications.
11. Twenty five ground water samples were collected each during pre- and post-monsoon seasons in the year 2006 and analysed for various physico-chemical and bacteriological parameters, heavy metals, pesticides and polynuclear aromatic hydrocarbons.
12. The hydro-chemical and bacteriological data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified.
13. The quality of the ground water varies from place to place with the depth of water table.
14. The bacteriological analysis of the samples indicates some sign of bacterial contamination at few locations. Inadequate maintenance of hand pump, improper sanitation and unhygienic conditions around the structure may be responsible for

bacterial contamination at these locations.

15. Pesticide analysis indicated the presence of some chlorinated pesticides at certain locations but their content was well within the permissible limits for drinking water at most of the locations. No organo-phosphorous pesticides and polynuclear aromatic hydrocarbons were detected in any of the ground water samples of the metropolitan cities.
16. The suitability of ground water for irrigation purpose has been evaluated based on salinity, Sodium Adsorption Ration (SAR), Residual Sodium Carbonate (RSC) and boron content.
17. An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram, Durov's plot, U.S. Salinity Laboratory and Gupta's classification.
18. The results of the study have been presented in tabular as well as graphical forms. Percentage distribution of samples for various water quality parameters in ground water of metropolitan cities have been summarized in the tables.

**Percentage Distribution of Samples for Various Water Quality Parameters in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (mg/L) | Metropolitan Cities | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Faridabad | Delhi | Jaipur | Bhopal | Indore | Jabalpur | Nagpur |
| 1 | TDS | 0-500 | 4 (4) | 20(28) | 44(48) | 24(44) | 12(12) | 48(68) | 16(24) |
| | | 500-2000 | 72(76) | 72(72) | 56(52) | 76(56) | 88(88) | 52(32) | 84(76) |
| | | **>2000** | **24(20)** | **8(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 2 | Alkalinity | 0-200 | 4(4) | 8(24) | 64(76) | 24(24) | (4) | 16(36) | 8(20) |
| | | 200-600 | 84(92) | 92(76) | 36(24) | 76(76) | 100(96) | 84(64) | 92(80) |
| | | **>600** | **12(4)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 3 | Hardness | 0-300 | 16(24) | 40(52) | 48(48) | 48(60) | 40(52) | 72(68) | 52(64) |
| | | 300-600 | 48(52) | 52(40) | 28(36) | 48(40) | 40(40) | 28(32) | 40(28) |
| | | **>600** | **36(24)** | **8(8)** | **24(16)** | **4(-)** | **20(8)** | **-(-)** | **8(8)** |
| 4 | Calcium | 0-75 | 16(24) | 32(40) | 44(52) | 48(48) | 40(52) | 52(64) | 48(60) |
| | | 75-200 | 52(52) | 60(52) | 48(44) | 44(48) | 48(40) | 48(36) | 40(36) |
| | | **>200** | **32(24)** | **8(8)** | **8(4)** | **8(4)** | **12(8)** | **-(-)** | **8(4)** |
| 5 | Magnesium | 0-30 | 48(64) | 60(84) | 40(52) | 88(84) | 56(72) | 96(96) | 72(76) |
| | | 30-75 | 52(36) | 36(16) | 48(40) | 12(16) | 44(28) | 4(4) | 24(20) |
| | | **>75** | **-(-)** | **4(-)** | **12(8)** | **-(-)** | **-(-)** | **-(-)** | **4(4)** |
| 6 | Chloride | 0-250 | 56(56) | 60(68) | 80(88) | 100(100) | 80(84) | 100(100) | 92(92) |
| | | 250-1000 | 44(44) | 36(32) | 20(12) | **-(-)** | 20(16) | **-(-)** | **8(8)** |
| | | **>1000** | **-(-)** | **4(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 7 | Sulphate | 0-200 | 64(68) | 88(88) | 100(100) | 100(100) | 100(100) | 100(100) | 92(92) |
| | | 200-400 | 24(20) | 8(8) | **-(-)** | **-(-)** | **-(-)** | **-(-)** | 4(4) |
| | | **>400** | **12(12)** | **4(4)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(4)** |
| 8 | Nitrate | 0-45 | 100(100) | 80(96) | 36(44) | 60(72) | 60(72) | 92(92) | 72(76) |
| | | 45-100 | **-(-)** | 16**(-)** | 24(20) | 28(24) | 20(20) | 8(8) | 24(20) |
| | | **>100** | **-(-)** | **4(4)** | **40(36)** | **12(4)** | **20(8)** | **-(-)** | **4(4)** |
| 9 | Fluoride | 0-1.0 | 60(72) | 52(76) | 20(44) | 100(88) | 96(96) | 52(72) | 52(92) |
| | | 1.0-1.5 | 24(16) | 28(4) | 40(48) | -(12) | 4**(-)** | 36(28) | 48(8) |
| | | **>1.5** | **16(12)** | **20(20)** | **40(8)** | **-(-)** | **-(4)** | **12(-)** | **-(-)** |

**Percentage Distribution of Samples for Various Water Quality Parameters in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (mg/L) | Metropolitan Cities | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Nasik | Pune | Bangalore | Hyderabad | Vishakhapatnam | Patna | Kochi |
| 1 | TDS | 0-500 | 8(28) | 68(60) | 44(56) | 4(16) | -(12) | 72(80) | 80(72) |
| | | 500-2000 | 92(72) | 32(40) | 52(40) | 92(84) | 92(80) | 28(20) | 20(28) |
| | | **>2000** | **-(-)** | **-(-)** | **4(4)** | **-(-)** | **8(8)** | **-(-)** | **-(-)** |
| 2 | Alkalinity | 0-200 | 20(24) | 60(56) | 64(68) | 12(24) | 12(24) | 20(56) | 88(76) |
| | | 200-600 | 80(76) | 40(44) | 36(32) | 84(76) | 84(76) | 80(44) | 12(24) |
| | | **>600** | **-(-)** | **-(-)** | **-(-)** | **4(-)** | **4(-)** | **-(-)** | **-(-)** |
| 3 | Hardness | 0-300 | 40(48) | 76(68) | 72(76) | 20(36) | 40(48) | 84(96) | 88(88) |
| | | 300-600 | 56(52) | 20(28) | 20(16) | 72(60) | 56(48) | 16(4) | 12(12) |
| | | **>600** | **4(-)** | **4(4)** | **8(8)** | **8(4)** | **4(4)** | **-(-)** | **-(-)** |
| 4 | Calcium | 0-75 | 44(44) | 64(56) | 16(80) | 16(16) | 32(32) | 76(84) | 88(84) |
| | | 75-200 | 48(56) | 32(40) | 28(16) | 80(80) | 64(64) | 24(16) | 12(16) |
| | | **>200** | **8(-)** | **4(4)** | **4(4)** | **4(4)** | **4(4)** | **-(-)** | **-(-)** |
| 5 | Magnesium | 0-30 | 76(88) | 96(92) | 76(76) | 72(88) | 92(76) | 92(96) | 100(96) |
| | | 30-75 | 24(12) | 4(8) | 24(24) | 28(12) | 8(20) | 8(4) | -(4) |
| | | **>75** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(4)** | **-(-)** | **-(-)** |
| 6 | Chloride | 0-250 | 96(96) | 96(96) | 84(84) | 96(96) | 84(84) | 100(100) | 92(92) |
| | | 250-1000 | 4(4) | 4(4) | 16(16) | 4(4) | 12(12) | -(-) | 8(8) |
| | | **>1000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(4)** | **-(-)** | **-(-)** |
| 7 | Sulphate | 0-200 | 96(96) | 96(96) | 96(96) | 92(92) | 88(88) | 100(100) | 100(100) |
| | | 200-400 | 4(4) | 4(4) | 4(4) | 8(8) | 8(8) | -(-) | -(-) |
| | | **>400** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(4)** | **-(-)** | **-(-)** |
| 8 | Nitrate | 0-45 | 52(68) | 92(92) | 80(80) | 16(44) | 36(44) | 84(88) | 92(96) |
| | | 45-100 | 44(28) | 4(4) | 12(12) | 72(48) | 40(32) | 16(12) | 4(4) |
| | | **>100** | **4(4)** | **4(4)** | **8(8)** | **12(8)** | **24(24)** | **-(-)** | **4(-)** |
| 9 | Fluoride | 0-1.0 | 92(96) | 96(96) | 92(100) | 16(60) | 80(84) | 88(88) | 96(100) |
| | | 1.0-1.5 | 8(4) | 4(4) | 8**(-)** | 8(12) | 16(16) | 4(12) | 4(-) |
| | | **>1.5** | **-(-)** | **-(-)** | **-(-)** | **76(28)** | **4(-)** | **8(-)** | **-(-)** |

**Percentages Distribution of Samples for Various Metal Ions in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (µg/L) | Metropolitan Cities | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Faridabad | Delhi | Jaipur | Bhopal | Indore | Jabalpur | Nagpur |
| 1 | Iron | 0-300 | 36(-) | 60(52) | 20(28) | 36(12) | 44(32) | 20(4) | 8(16) |
| | | 300-1000 | 36(16) | 28(20) | 36(40) | 48(32) | 40(48) | 52(48) | 40(44) |
| | | **> 1000** | **28(84)** | **12(28)** | **44(32)** | **16(56)** | **16(20)** | **28(48)** | **52(40)** |
| 2 | Manganese | 0-100 | 68(60) | 72(72) | 92(96) | 100(96) | 96(92) | 52(44) | 80(6) |
| | | 100-300 | 8(32) | 12(12) | 4(4) | -(4) | 4(8) | 24(40) | 12(20) |
| | | **> 300** | **24(8)** | **16(16)** | **4(-)** | **-(-)** | **-(-)** | **24(16)** | **8(4)** |
| 3 | Copper | 0-50 | 96(92) | 100(100) | 96(96) | 100(92) | 92(100) | 100(96) | 88(100) |
| | | 50-1500 | 4(8) | -(-) | 4(4) | -(8) | 8(-) | -(4) | 12(-) |
| | | **> 1500** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 4 | Chromium | 0-50 | 96(100) | 100(100) | 100(100) | 100(100) | 100(100) | 100(100) | 100(100) |
| | | **> 50** | **4(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 5 | Lead | 0-50 | 48(72) | 88(88) | 92(80) | 92(100) | 96(88) | 100(100) | 80(92) |
| | | **> 50** | **52(28)** | **12(12)** | **8(20)** | **8(-)** | **4(12)** | **-(-)** | **20(8)** |
| 6 | Cadmium | 0-10 | 76(68) | 96(80) | 88(100) | 100(100) | 96(92) | 88(100) | 92(72) |
| | | **> 10** | **24(32)** | **4(20)** | **12(-)** | **-(-)** | **4(8)** | **12(-)** | **8(28)** |
| 7 | Zinc | 0-5000 | 92(100) | 100(96) | 100(100) | 96(92) | 100(96) | 100(100) | 100(100) |
| | | 5000-15000 | 8(-) | -(4) | -(-) | 4(8) | -(4) | -(-) | -(-) |
| | | **> 15000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |

**Percentages Distribution of Samples for Various Metal Ions in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (µg/L) | Metropolitan Cities | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Nasik | Pune | Bangalore | Hyderabad | Vishakhapatnam | Patna | Kochi |
| 1 | Iron | 0-300 | 24(60) | 56(56) | 88(96) | 88(96) | 92(80) | 24(24) | 24(-) |
| | | 300-1000 | 48(32) | 36(36) | 12(4) | 12(4) | 4(8) | 56(64) | 44(52) |
| | | **> 1000** | **28(8)** | **8(8)** | **-(-)** | **-(-)** | **4(12)** | **20(12)** | **32(48)** |
| 2 | Manganese | 0-100 | 92(88) | 92(68) | 88(80) | 88(80) | 88(92) | 60(76) | 76(40) |
| | | 100-300 | 4(8) | -(16) | 8(12) | 8(12) | 4(4) | 40(24) | 16(48) |
| | | **> 300** | **4(4)** | **8(16)** | **4(8)** | **4(8)** | **8(4)** | **-(-)** | **8(12)** |
| 3 | Copper | 0-50 | 100(96) | 96(100) | 100(100) | 100(100) | 100(100) | 96(92) | 100(96) |
| | | 50-1500 | -(4) | 4(-) | -(-) | -(-) | -(-) | 4(8) | -(4) |
| | | **> 1500** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 4 | Chromium | 0-50 | 92(96) | 100(96) | 100(100) | 100(100) | 100(100) | 100(100) | 100(100) |
| | | **> 50** | **8(4)** | **(4)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 5 | Lead | 0-50 | 92(92) | 92(100) | 92(92) | 92(92) | 88(96) | 96(96) | 100(92) |
| | | **> 50** | **8(8)** | **8**(-) | **8(8)** | **8(8)** | **12(4)** | **4(4)** | **-(8)** |
| 6 | Cadmium | 0-10 | 64(76) | 96(100) | 64(60) | 64(60) | 12(84) | 88(88) | 100(92) |
| | | **> 10** | **36(24)** | **4**(-) | **36(40)** | **36(40)** | **88(16)** | **12(12)** | **-(8)** |
| 7 | Zinc | 0-5000 | 92(96) | 100(96) | 96(92) | 96(92) | 92(96) | 100(100) | 100(100) |
| | | 5000-15000 | 8(4) | -(4) | 4(8) | 34(8) | 4(4) | -(-) | -(-) |
| | | **> 15000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(-)** | **-(-)** | **-(-)** |

Values given in parentheses represent post-monsoon data.

| S.No. | Parameter | Range (mg/L) | Metropolitan Cities | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ahmedabad | Rajkot | Surat | Vadodara | Asansol |
| 1 | TDS | 0-500 | 8(12) | -(-) | 24(24) | 4(4) | 16(20) |
| | | 500-2000 | 88(88) | 100(100) | 44(68) | 88(96) | 84(80) |
| | | **>2000** | **4(-)** | **-(-)** | **32(8)** | **8(-)** | **-(-)** |
| 2 | Alkalinity | 0-200 | 8(12) | 20(40) | 20(32) | 4(8) | 20(24) |
| | | 200-600 | 88(88) | 80(60) | 72(68) | 88(84) | 80(76) |
| | | **>600** | **4 (-)** | **-(-)** | **8(-)** | **8(8)** | **-(-)** |
| 3 | Hardness | 0-300 | 48(60) | -(8) | 32(44) | 20(36) | 24(36) |
| | | 300-600 | 48(36) | 68(64) | 36(40) | 68(52) | 64(52) |
| | | **>600** | **4(4)** | **32(28)** | **32(16)** | **12(12)** | **12(12)** |
| 4 | Calcium | 0-75 | 68(68) | 28(20) | 80(84) | 48(52) | 48(40) |
| | | 75-200 | 28(32) | 60(72) | 20(12) | 40(48) | 44(60) |
| | | **>200** | **4(-)** | **12(8)** | **-(4)** | **12(-)** | **8(-)** |
| 5 | Magnesium | 0-30 | 24(32) | 8(12) | 8(20) | 28(28) | 36(20) |
| | | 30-75 | 68(64) | 72(60) | 36(48) | 60(56) | 64(76) |
| | | **>75** | **8(4)** | **20(28)** | **56(32)** | **12(16)** | **-(4)** |
| 6 | Chloride | 0-250 | 96(88) | 68(72) | 44(60) | 84(88) | 96(92) |
| | | 250-1000 | 4(12) | 32(28) | 40(32) | 16(12) | 4(8) |
| | | **>1000** | **-(-)** | **-(-)** | **16(8)** | **-(-)** | **-(-)** |
| 7 | Sulphate | 0-200 | 84(84) | 96(88) | 84(96) | 96(96) | 92(92) |
| | | 200-400 | 12(16) | 4(12) | 12(-) | -(-) | 8(8) |
| | | **>400** | **4(-)** | **-(-)** | **4(4)** | **4(4)** | **-(-)** |
| 8 | Nitrate | 0-45 | 52(88) | 28(28) | 88(60) | 72(96) | 76(72) |
| | | 45-100 | 16(4) | 28(44) | 4(40) | 12(-) | 12(12) |
| | | **>100** | **32(8)** | **44(28)** | **8(-)** | **16(4)** | **12(16)** |
| 9 | Fluoride | 0-1.0 | 80(60) | 100(100) | 96(96) | 76(80) | 92(92) |
| | | 1.0-1.5 | 20(32) | -(-) | 4(4) | 24(20) | 8(8) |
| | | **>1.5** | **-(8)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |

Values given in parentheses represent post-monsoon data.

**Percentage Distribution of Samples for Various Water Quality Parameters in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (mg/L) | Metropolitan Cities | | | | |
|---|---|---|---|---|---|---|---|
| | | | Dhanbad | Jamshedpur | Kolkata | Amritsar | Kanpur |
| 1 | TDS | 0-500 | 36(40) | 32(36) | -(4) | 40(56) | 12(20) |
| | | 500-2000 | 64(60) | 68(64) | 100(96) | 60(44) | 88(80) |
| | | **>2000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 2 | Alkalinity | 0-200 | 60(60) | 60(48) | -(4) | 8(20) | -(16) |
| | | 200-600 | 40(40) | 40(52) | 100(96) | 92(80) | 96(84) |
| | | **>600** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(-)** |
| 3 | Hardness | 0-300 | 36(36) | 32(44) | 16(16) | 68(68) | 40(52) |
| | | 300-600 | 52(52) | 60(48) | 48(52) | 32(32) | 52(48) |
| | | **>600** | **12(12)** | **8(8)** | **36(32)** | **-(-)** | **8(-)** |
| 4 | Calcium | 0-75 | 52(44) | 40(48) | 32(32) | 76(68) | 48(72) |
| | | 75-200 | 44(52) | 52(44) | 36(52) | 24(32) | 52(28) |
| | | **>200** | **4(4)** | **8(8)** | **32(16)** | **-(-)** | **-(-)** |
| 5 | Magnesium | 0-30 | 44(36) | 32(44) | 24(20) | 60(92) | 32(36) |
| | | 30-75 | 56(60) | 68(56) | 76(64) | 40(8) | 60(56) |
| | | **>75** | **-(4)** | **-(-)** | **-(16)** | **-(-)** | **8(8)** |
| 6 | Chloride | 0-250 | 100(100) | 100(100) | 44(44) | 100(100) | 96(92) |
| | | 250-1000 | -(-) | -(-) | 56(56) | -(-) | 4(8) |
| | | **>1000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 7 | Sulphate | 0-200 | 96(96) | 92(92) | 100(+) | 100(100) | 96(92) |
| | | 200-400 | 4(4) | 8(8) | -(-) | -(-) | 4(8) |
| | | **>400** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 8 | Nitrate | 0-45 | 88(64) | 80(100) | 100(100) | 88(72) | 96(96) |
| | | 45-100 | 4(24) | 4(-) | -(-) | -(12) | -(20) |
| | | **>100** | **8(12)** | **16(-)** | **-(-)** | **12(16)** | **4(-)** |
| 9 | Fluoride | 0-1.0 | 96(92) | 96(100) | 96(100) | 84(84) | 84(48) |
| | | 1.0-1.5 | 4(8) | 4(-) | 4(-) | 16(4) | 4(44) |
| | | **>1.5** | **-(-)** | **-(-)** | **-(-)** | **-(12)** | **12(8)** |

Values given in parentheses represent post-monsoon data.

**Percentages Distribution of Samples for Various Metal Ions in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (µg/L) | Metropolitan Cities | | | | |
|---|---|---|---|---|---|---|---|
| | | | Ahmedabad | Rajkot | Surat | Vadodara | Asansol |
| 1 | Iron | 0-300 | -(56) | 8(16) | 16(24) | 8(4) | 8(4) |
| | | 300-1000 | 40(24) | 48(28) | 36(36) | 12(20) | 8(36) |
| | | **> 1000** | **60(20)** | **44(56)** | **48(40)** | **80(76)** | **84(64)** |
| 2 | Manganese | 0-100 | 96(88) | 80(76) | 60(84) | 72(76) | 52(100) |
| | | 100-300 | 4(12) | 20(24) | 24(12) | 28(16) | 28(-) |
| | | **> 300** | **-(-)** | **-(-)** | **16(4)** | **-(8)** | **20(-)** |
| 3 | Copper | 0-50 | 92(100) | 92(100) | 100(96) | 88(96) | 92(100) |
| | | 50-1500 | 8(-) | 8(-) | -(4) | 12(4) | 8(-) |
| | | **> 1500** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 5 | Chromium | 0-50 | 100(96) | 92(92) | 100(100) | 100(100) | 100(100) |
| | | **> 50** | **-(4)** | **8(8)** | **-(-)** | **-(-)** | **-(-)** |
| 6 | Lead | 0-50 | 96(100) | 88(84) | 84(76) | 88(80) | 92(80) |
| | | **> 50** | **4(-)** | **12(16)** | **16(24)** | **12(20)** | **8(20)** |
| 7 | Cadmium | 0-10 | 88(96) | 92(100) | 68(100) | 96(92) | 100(100) |
| | | **> 10** | **12(4)** | **8(-)** | **32(-)** | **4(8)** | **-(-)** |
| 8 | Zinc | 0-5000 | 96(100) | 96(100) | 100(100) | 100(100) | 96(100) |
| | | 5000-15000 | 4(-) | 4(-) | -(-) | -(-) | 4(-) |
| | | **> 15000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 9 | Arsenic | 0-50 | 100(100) | 100(100) | 100(100) | 60(92) | 100(100) |
| | | **>50** | **-(-)** | **-(-)** | **-(-)** | **40(8)** | **-(-)** |
| 10 | Mercury | 0-1 | 96(100) | 100(100) | 92(100) | 96(100) | 96(100) |
| | | **>1** | **4(-)** | **-(-)** | **8(-)** | **4(-)** | **4(-)** |

Values given in parentheses represent post-monsoon data.

**Percentages Distribution of Samples for Various Metal Ions in Ground Water of Metropolitan Cities**

| S.No. | Parameter | Range (µg/L) | Metropolitan Cities | | | | |
|---|---|---|---|---|---|---|---|
| | | | Dhanbad | Jamshed-pur | Kolkata | Amritsar | Kanpur |
| 1 | Iron | 0-300 | 4(12) | 4(-) | 4(4) | 24(4) | 16(24) |
| | | 300-1000 | 28(44) | 40(8) | 32(24) | 32(8) | 24(40) |
| | | **> 1000** | **68(44)** | **56(92)** | **64(72)** | **44(88)** | **60(36)** |
| 2 | Manganese | 0-100 | 36(68) | 12(12) | 24(28) | 40(16) | 64(72) |
| | | 100-300 | 24(16) | 32(32) | 12(16) | 40(80) | 36(24) |
| | | **> 300** | **40(16)** | **56(56)** | **64(56)** | **20(4)** | **-(4)** |
| 3 | Copper | 0-50 | 96(100) | 88(84) | 96(96) | 84(72) | 96(96) |
| | | 50-1500 | 4(-) | 12(16) | 4(4) | 16(28) | 4(4) |
| | | **> 1500** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 5 | Chromium | 0-50 | 100(100) | 100(100) | 100(100) | 100(100) | 96(100) |
| | | **> 50** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **4(-)** |
| 6 | Lead | 0-50 | 100(100) | 100(92) | 100(84) | 88(84) | 100(88) |
| | | **> 50** | **-(-)** | **-(8)** | **-(16)** | **12(16)** | **-(12)** |
| 7 | Cadmium | 0-10 | 100(100) | 92(100) | 72(100) | 96(100) | 96(100) |
| | | **> 10** | **-(-)** | **8(-)** | **28(-)** | **4(-)** | **4(-)** |
| 8 | Zinc | 0-5000 | 100(100) | 100(100) | 80(72) | 100(96) | 100(100) |
| | | 5000-15000 | -(-) | -(-) | 20(28) | -(4) | -(-) |
| | | **> 15000** | **-(-)** | **-(-)** | **-(-)** | **-(-)** | **-(-)** |
| 9 | Arsenic | 0-50 | 96(100) | 100(100) | 64(96) | 100(100) | 100(100) |
| | | **>50** | **4(-)** | **-(-)** | **36(4)** | **-(-)** | **-(-)** |
| 10 | Mercury | 0-1 | 76(96) | 96(100) | 28(92) | 100(100) | 84(100) |
| | | **>1** | **24(4)** | **4(-)** | **72(8)** | **-(-)** | **16(-)** |

Values given in parentheses represent post-monsoon data.

# 1.0 INTRODUCTION

In recent years, an increasing threat to ground water quality due to human activities has become of great importance. The adverse effects on ground water quality are the results of man's activity at ground surface, unintentionally by agriculture, domestic and industrial effluents, unexpectedly by sub-surface or surface disposal of sewage and industrial wastes.

The quality of ground water is of great importance in determining the suitability of particular ground water for a certain use (public water supply, irrigation, industrial applications, power generation etc.). The quality of ground water is the resultant of all the processes and reactions that have acted on the water from the moment it condensed in the atmosphere to the time it is discharged by a well. Therefore, the quality of ground water varies from place to place, with the depth of water table, and from season to season and is primarily governed by the extent and composition of dissolved solids present in it.

A vast majority of ground water quality problems are caused by contamination, over-exploitation, or combination of the two. Most ground water quality problems are difficult to detect and hard to resolve. The solutions are usually very expensive, time consuming and not always effective. Ground water quality is slowly but surely declining everywhere. Ground water pollution is intrinsically difficult to detect, since problem may well be concealed below the surface and monitoring is costly, time consuming and somewhat hit-or-miss by nature.

The wide range of contamination sources is one of the many factors contributing to the complexity of groundwater assessment. It is important to know the geochemistry of the chemical-soil-groundwater interactions in order to assess the fate and impact of pollutant discharged on to the ground. Pollutants move through several different hydrologic zones as they migrate through the soil to the water table. The serious implications of this problem necessitate an integrated approach in explicit terms to undertake ground water pollution monitoring and abatement programmes.

A major problem in urbanised areas is the collection and disposal of domestic wastes. Because a large volume of sewage is generated in a small area, the waste cannot be adequately disposed off by conventional septic tanks and cesspools. Therefore, special disposal sites are being used to collect and dispose such wastes in densely populated areas.

The intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and have already resulted in many incidents of ground water contamination. Pollutants are being added to the ground water system through human activities and natural processes. Solid waste from industrial units is being dumped near the factories, which is subjected to reaction with percolating rain water and reaches the ground water level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the ground water. The problem of ground water pollution in several parts of the country has become so acute that unless urgent steps for detailed identification and abatement are taken, extensive ground water resources may be damaged.

The quality of ground water depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportions of dissolved constituents are found in ground water than in surface water because of greater interaction of ground water with various materials in geologic strata. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders.

The contamination of ground water by heavy metals and pesticides has also assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals and pesticides in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today.

The Central Pollution Control Board (CPCB) has awarded the Project Study on 'Assessment of Ground Water Quality in twenty four Metropolitan Cities of the Country' to National Institute of Hydrology, Roorkee. In order to achieve the objectives of the study, ground water samples from the fourteen Metropolitan Cities were collected during 2004 representing various geo-hydrological and land use conditions during pre- and post-monsoon seasons in the year 2004 and analysed for various physico-chemical constituents, trace elements, pesticides, polynuclear aromatic hydrocarbons and bacteriological parameters. The data has been analysed with reference to BIS and WHO standards to examine the suitability of ground water for drinking and irrigation purposes. An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Piper trilinear diagram, Chadha's diagram, Durov's diagram, U.S. Salinity Laboratory classification and Gupta's classification. The results of the study for the 14 metropolitan cities have been presented in this report.

# 2.0 METROPOLITAN CITIES

## 2.1 Faridabad

Faridabad, one of the oldest towns in Haryana, is a bustling industrial town and is located at 28$^{o}$ 15' N latitude and 77$^{o}$ 13' 12" E longitude (Fig. 5.1.1). It has grown enormously during the last couple of decades, because a large number of industries have come up in the town. It is bounded by Delhi (National Capital) on its north, Gurgaon District on the west and state of Utter Pradesh on east and south. Delhi-Mathura National Highway No.2 (Shershah Suri Marg) passes through the centre of the city. Total area of the city is 216.4 km$^2$ with more or less flat surface. It is the thirty first largest town in India (population wise). The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Faridabad is 10,54,981.

### 2.1.1 Physiography and Drainage

The area of the city comprises plains to broken ridges at the north western side. These ridges attain a maximum elevation of about 318 m above m.s.l. The sand dunes are occurred 3-10 cm in height. The major river in the city is the Yamuna which is a perennial stream. Besides, numerous other streams come down from the hilly traces and discharge them into the plains. The Agra canal passes through the corner of the city and has several tributaries. The drainage of the city passes through these canals and finally joins with the river Yamuna.

### 2.1.2 Climate

The city experiences extreme conditions of summer and cold with maximum and minimum temperatures of 45 and 5ºC respectively. The summer period starts from April to June while the winter begins from October to March. The rainy season occurs from July to September with 562.9 mm as the maximum rain fall.

### 2.1.3 Geology

Faridabad is occupied by quaternary alluvium and pre-combrian sediments systems. The stratifgraphic units are wind blown sands, newer alluvium, older alluvium, slates, phyllites, quartzites, mica sheets, pagamite intrusions, silts, gravel, sand, clay and kankar.

### 2.1.4 Potential of Ground Water

The ground water is the major source for domestic, industrial and agriculture uses. The depth of water lies at about 10 m with shallow availability of ground water near Yamuna river. Water table ranges from 180 to 210 m above m.s.l. The aquifer thickness has been measured 15 to 40 m and these are composed of fine to coarse sand and clay with a little kankar. The principal ground water reservoir is the unconsolidated alluvial deposits of quaternary age.

## 2.1.5 Population

As per the 2001 census, the population of metropolitan city Faridabad is 10,54,981. The literacy rate in the city was 68.5% and the participation of the male was found to be 60.3% and that of the female was 39.7%. The city has a sex ratio of 817 females for every 1000 males.

## 2.1.6 Water Supply

Water supply in Faridabad city is from ground water through tube wells and hand pumps. Total water supply is 194.5 mld including 145.18 and 49.32 mld for domestic and industrial uses respectively. The population served is about 95% through 25 wards. The total tube wells are 378 in the city. Besides, there are some more private tube wells used for domestic and industrial purposes.

## 2.1.7 Waste Water Generation

Due to highly populated and industrial nature of the city it produces a waste water flow of about 145 mld. Before Yamuna Action Plan, about 70% of the area, falling mainly under the new industrial township area, was covered by sewerage facility. But the raw sewage was being pumped into storm water drains, which was ultimately carried through Gounchi drain to the river Yamuna. Sewage from the eastern side of Delhi-Mathura road, i.e. from HUDA and old Faridabad areas was being pumped to an treatment plant (oxidation pond) which was overloaded and thus non-functional. The effluent from the oxidation pond was being supplied to agricultural fields with the excess being pumped into Gurgaon canal.

The sewerage collection is through open drains and about 80% of the city is sewered. Pumping stations and sewage treatment facility are provided for the same. A swege treatment plant is working at Mirzapur. Solid waste generated is about 400 tones per day and is disposal at Mirzapur.

## 2.1.8 Status of Industries

At present about 15,000 small, medium and large scale industries are in operation, which has given a status to the city of 9$^{th}$ place in Asia. Various multinational companies like Whirlpool, Goodyear, Larsen & Toubro, Asia Brown Boveri, GKN Invel, Woodward Governer, Castrol besides Escorts, Eicher, Cutler Hammer, Hyderabad Asbestos, Nuchem are working in this belt. Some important industrial estates/areas along with the type of industries are summarized below.

| S.No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Sector 45 | Drugs & pharmaceuticals, plastics, metal casting, agriculture equipments, automobile parts, electricals, garments & other engineering industries |
| 2. | Sector 22 | plastic moulds for automobiles, electronics, computers, oil exploration, medical & other engineering industries |

| | | |
|---|---|---|
| 3. | Sector 6 | Packing industries, metal, chemical, fiber, dying, printing, machinery & other engineering industries |
| 4. | Sector 24 | Chemicals, petrochemicals, metals casting, plastics, metal castings, paints, rubber, pesticides & other engineering industries |
| 5. | Sector 25 | Drugs & pharmaceuticals, printing, agriculture equipment industries, chemical, fertilizer & other engineering industries |
| 6. | Sector 27 A-D | Light lift industries, packing, chemicals, plastic, plastics, garments, electrical, electronics & other engineering industries |
| 7. | Sector 58 | Chemicals, machine tools, automobile parts, printing, metal processing, wires, cement pipes & other engineering industries |
| 8. | Sector 59 | Automobiles & other engineering industries |
| 9. | Sector 2 | Gas, chemicals & other engineering industries |
| 10. | DLF Indst. Area | Printing, automobiles, chemicals, brushes, sports, machine tools, rubber, packing, pharmaceuticals, brass wares, industrial equipments & other engineering industries |
| 11. | Sector 13 | Oil processing industries, metal casting, automobile parts & other engineering industries |
| 12. | Mirzapur | Thermal power plant |

## 2.1.9 Petroleum Storage

There is no petroleum storage in Faridabad city and the demand of the petrol/diesel is completed from various depots situated at Delhi. However, about 25 petrol pumps have been identified which serve the need of people for petrol and diesel. These petrol pumps belong to Hindustan Petroleum Ltd., Indian Oil Corporation Ltd. and Bharat Petroleum Corporation Ltd.

## 2.2 Delhi

Delhi being the capital of India and a state itself is very important metropolitan city by administrative, industrial and trade point of view. It has six administrative blocks, viz., Alipur, Kanjhawala, Najafgarh, Mehrauli, City and Shahadra. The city is located at 28$^o$22'48"N latitude and 77°7'12"E longitude and occupies an area of about 1483 km$^2$ (Fig. 5.2.1). It is the third largest town in India (population wise). The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Delhi is 1,27,91,458.

## 2.2.1 Physiography and Drainage

Delhi consists of flat and level plains interrupted by cluster of sand dunes and a long continuous chain of rocky ridges. The sand dunes are of varying dimensions and in general trend northeast - southwest. The crests of the dunes generally lie between 6 and 15 meter above the surrounding plains. They are more or less fixed in this area and support vegetation. It appears that they are of longitudinal type and are oriented parallel to the prevailing wind directions. Delhi metropolitan city is situated to northern-western part of India at northern most extension of Aravali mountain range. General stratigraphic sequence in Delhi are newer alluvium, older alluvium and quartzies. The agriculture land use has changed repeatedly and is shifter to other uses. Delhi being highly urbanized contains huge area pavmented and, hence, a huge amount of surface water is generated during precipitation. The run-off occurs through various drains and nallahs and finally gets discharge into the Yamuna river. Some important drains are eastern and western Yamuna canals and Agra canal, Bawana, Rajpur and Lampur distributaries. Auchandi, Budhanpur, Sultanpur Mundka, Mongolpur, Nahari, Dhansa and Surkhpur are some of important minors. The Agra canal originates from Okhla, about 12 km. South of Delhi. Some part of runoff also contributes to sub soil water and recharge. The run-off coefficients were reported 31% and 21% in urban and other areas respectively.

## 2.2.2 Climate

Delhi has an extreme climate as of plain of northern India with all seasonal changes of temperature, rainfall, wind pattern etc. through the year. Delhi is a land locked city and the distance from the sea gives it an extreme type of continental climate. The summers in Delhi are very hot and winters very cold. The temperature range varies from 45ºC in summers to 4ºC in winters. The winter is marked by mist and fog in the mornings and often sun is seen in the afternoons. The cold wave from the Himalayan region makes winter very chilly. In summers the heat wave is immense. The average rainfall in the city is about 61.18 cm. About 80% rainfall is received during rainy season.

## 2.2.3 Geology

The geology of Delhi is of mix type containing various soil deposits. It consists of quartz rock and extends from south part to west bank of the Yamuna river for about 35 km. The soil textures in Delhi are alluvial and quartz type. The Yamuna river flood carried different types of soils and, hence, at some places the soil is a mixture of various constituents. General stratigraphic sequences of the rock formation in Delhi are unconsolidated, inter bedded, sand lenses, silt, gravel, clay, kankar and quartz. The Yamuna is the only river flows through the city and it enters into Delhi at north-west side and leave at south-east end. The soils of the Delhi area are mostly light with subordinate amount of medium texture soils. The light texture soils are represent by sandy, loamy, and sandy loam types; whereas medium texture soils are represented by loam silty loam.

## 2.2.4 Potential of Ground Water

The ground water availability in Delhi is controlled by the hydrogeological formations characterized by the presence of alluvial formation and quartzitic hard rocks. Total groundwater availability in Delhi is about 291.44 MCM/year and it is used for irrigation, industrial and drinking purposes; up to some extent. The rock formation is widely varied with variation in land formation like ridge areas. It is traversing across the city and is quite significant to control the occurrence and movement of groundwater. In shallow aquifers, the groundwater occurs under phreatic confined condition. Contrarily, it is in semi-confined to confined conditions in deep aquifers. The shallow aquifers contain saline water and the depth varies from 5 to 10 m. The deeper aquifers vary from 20 to 50 m. A decline in water table of 4 m has been observed in Delhi for last few decades.

## 2.2.5 Population

As per the 2001 census, the population of metropolitan city Delhi is 1,27,91,458. According to 2001 census, the literacy rate in the city was 70.8% and the participation of the male was found to be 58.7% and that of the female was 41.3%. The city has a sex ratio of 822 females for every 1000 males.

## 2.2.6 Water Supply

Water requirement for drinking purpose of Delhi is mainly met from river Yamuna. However, groundwater is also used for drinking purpose in few areas. The main use of groundwater is in agriculture, horticulture and industries. Water from the Yamuna is treated by two treatment plants. These are situated at Chandrawal and Wazirabad areas. Water is directly taken from the Yamuna through pumping. The treatment of water includes primary treatment i.e. sedimentation, filtration and chlorination. These plants carry out no secondary and tertiary treatment. The total domestic water consumption is about 226 lcd which is supplied through various pumping stations.

## 2.2.7 Waste Water Generation

The municipal wastewater generated is the major water pollution load of Delhi. About 1.99 and 0.32 MCM/day of wastewater is generated from municipal and industrial sectors respectively. Delhi Jal Board is responsible for treatment and disposal of wastewater through an efficient network of about 5600 km of internal, peripheral and trunk-sewers. The capacity of Sewage Treatment Plants has been raised from 0.922 MCM/day (376.4 MGD) to 0.985 MCM/day (402.4 MGD) during the year 2000-2001. About 17 Sewage Treatment Plants are working into the city**.** The capacity of the present wastewater treatment plants in Delhi is 1.27 MCM/day which indicates that about 1.04 MCM/day wastewater is disposed of as such. Moreover, only primary wastewater treatment is carried out in these wastewater treatment plants; with exception in few where secondary treatment facility exists. No treatment plant is equipped with tertiary water treatment facility. In this way, the untreated or partially treated wastewater is discharged in to the Yamuna river.

## 2.2.8 Status of Industries

Delhi being capital and a center of trade contains many small and medium size industries. These units are located into several pockets metropolitan city of Delhi. The number of these industries is increasing rapidly. The major industries are of engineering goods, textile, chemical, electronics, electrical goods, dyes and paints, steel, plastic, rubber, automobiles, etc. Besides, there are four thermal power stations out of which three are driven of by coal one by gas. These thermal power stations are Badarpur thermal power station, Indraparsth thermal power station, Rajghat thermal power station and Gas turbine thermal power station. Various industrial development authorities of government of India monitor the development and growth of industries. Most industries are located at west, south and east of the city. Besides, several other industries are located in unorganized manner in non-conforming areas. Some important industries along with their areas are summarized below.

| S.No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Wazirpur | Plastic, textile, chemicals, steel & Dyes |
| 2. | Lawrence Road | Textiles, plastics, steel, paints & other small units |
| 3. | G.T. Karnal Road | Plastics, chemicals & other engineering units |
| 4. | SSI Indst. Area | Plastic, chemicals, hosiery & other small units |
| 5. | SMA Indst. Area | Plastics, chemicals & other engineering units |
| 6. | Najafgarh Road | Plastic, paints, hosiery, textile, chemicals & pesticides |
| 7. | Anand Parvat | Automobiles, electroplating & other small units |
| 8. | Jhandewalan | Electronic & other small units |
| 9. | Kirti Nagar | Steel, automobiles, chemicals & furniture |
| 10. | Moti Nagar | Steel, chemicals, textiles & plastic |
| 11. | Mangolpuri | Textiles, plastics, automobiles electroplating & other small units |
| 12. | Narela | Textiles, plastics & other small units |
| 13. | Rajasthan Udyog Nagar | Textiles, plastic, hosiery & automobiles |
| 14. | Shadra | Rubber, chemicals, battery & wire |
| 15. | Jhilmil | Plastic, chemicals & rubber |
| 17. | Mayapuri | Plastic, rubber & other engineering |
| 18. | Nangloi | Plastic, textile, wires & hosiery |
| 19. | Naraina | About 500 medium size units of engineering works |
| 20. | Tilak Nagar | Plastic & other small units |
| 21. | Udyog Nagar | Plastic & other small units |
| 22. | Okhla | Textile, plastic, furniture, detergents, chemicals & dyes |
| 23. | Flatted Factory Complex | Electrical & electronics |
| 24. | Mohan Co-operative | Plastic, hosiery & other small units |
| 25. | Friend Colony | Textiles, electronics & other small units |
| 26. | G.T. Karnal Road | Plastic, electronics, wires, hosiery & other small units |
| 27. | Badli | Electronics, textile, plastic, detergents, wires, chemicals & hosiery |
| 28. | Pipalthala | Textile, plastic & rolling Mills |

### 2.2.9 Petroleum Storage

There are three petroleum storages in Delhi, Hindustan Petroleum Corporation Ltd., Punjabi Bagh; Indian Oil Corporation Ltd., Bijwasan and Bharat Petroleum Corporation Ltd.

## 2.3 Jaipur

The metropolitan city of Jaipur is the capital of Rajasthan and is known as pink city of India. The metropolitan city is located at $26^{o}33'$ N latitude and $75^{o}31'12''$E longitude and occupies an area of about 230 $km^2$ (Fig. 5.3.1). It is the $11^{th}$ largest town in India (population wise), and the largest in the state of Rajasthan. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Jaipur is 23,24,319.

### 2.3.1 Physiography and Drainage

A large part of district is covered by thick mantle of soil, brown sand and alluvium in eastern and northern area is occupied by hills range and belongs to Aravalli system and are known by different names at different places, the longest range starting from Sambhar lake in this district crosses over upto Singhana in the district of Jhunjhunun.

The district is drained by a number of largely non-perennial rivers of which Banganga and Sabi are important one. The Banganga has been impounded near Jamwa Ramgarh which provides a major share of drinking water supplies to Jaipur city. A large area of the district has been affected by sand encroachment through wind gaps and river valleys.

### 2.3.2 Climate

The climate of the city is dry and healthy and is subjected to extremes of cold and heat at various places. The minimum and maximum temperatures are 3°C and 45°C respectively while the mean temperature is 24°C. The normal annual rainfall in the district is 548 mm.

### 2.3.3 Geology

The oldest groups of rock in the district are schist, gneisses, migmatite and quartzite of Pre-Aravalli, which are considered to be nearly 2,500 million year old. These rocks are covered under a mantle of sand and alluvium, of recent to sub recent age. Overlying these rocks with a major unconfirmity are the rocks of Delhi super group, which are made up of Rialo, Alwar and Ajabgarh group. The rocks of Rialo comprise mainly dolomitic marble and minor quartzite. The Alwar group consists of conglomeratic quartzites and schist which either lie unconfirmably over the Rialo or directly over the metamorphic of Pre-Aravalli. The Ajabgarh group is mainly made up of schists, phyllites, pegmatites and quartz veins.

A variety of mineral deposits found in the region are Chinaclay in Buchara and Torda, Copper near Gol, Badshahpur, Chanla and Chatigodlyana area, Iron ore near Moriza, Bonai etc. Cement grade limestone near Kotputli and Maonda and impure lime stone at Nimala, Dabla etc. Silica sand is found at Banskhop and Jir hills. Soapstone occurs in Dogetha, Jharna and Geejgarh.

### 2.3.4 Potential of Ground Water

The main hydrogeological set up in the region is quaternary alluvium which covers entire Sanganer blocks and spreads in major part of Sambhar, Phagi, Dudu, Chaksu and Bassi blocks. Quartzite occurs as small localized pocket in Amer, Bassi, Jamwa Ramgarh and Kotputli blocks. Phyllite and schist occupy small area in southern peripheral part in Dudu, Jamwa Ramgarh and Phagi blocks. Granite and gneiss cover extensive area in Dudu block and extends in western peripheral part of Phagi block. There is significant variation in direction of ground water flow. In northern part, it is SW to NE. Near Shahpura, there is a ground water basin. In other part, ground water flow has been inferred N to S with variation from NNE to SSW or NNW to SSE. Hydraulic gradient in southern part and near Shahpura varies from 1.33 to 13.33 m/km.

## 2.3.5 Population

As per the 2001 census, the population of metropolitan city Jaipur is 23,24,319. The literacy rate in the city was 67.1% and the participation of the male was found to be 59.0% and that of the female was 41.0%. The city has a sex ratio of 875 females for every 1000 males.

## 2.3.6 Water Supply

According to Public Health Engineering Department, Jaipur, the daily drinking water supply of Jaipur city is 330 mld, out of which 290 mld is being used for domestic purpose and the remaining 40 mld is being used for industrial and non-domestic purposes. The actual demand is 150 lpcd and actual per capita supply is 149 lpcd. 98.2% of the supply is through ground source and 1.8% through surface source. 64.5% population is covered by sewerage system. The total number of tube well installed by PHED is 1218, out of which 1218 are operational. The total number of hand pumps existing in the city is 1777, out of which 1736 are operational. There are 48 overhead tanks of 40 mld capacity.

## 2.3.7 Waste Water Generation

The total solid waste generated in the municipal area of the city is 1040 MT/day. Land fill sites exists at Mathuradas Pura, Sewage farm (New Sanganer Road) and Sewapura (Chandrabaji). There is one Common Treatment Plant (CTP) in Khori Upaidi.

## 2.3.8 Status of Industries

There are about ten industrial areas with different types of small scale industrial and artizen units in the city. Industrial areas comprises of Marbel units, Readymade garments, Rolling mills, Chemical units, Printing units, Powerloom units, Gems and Jewelry unit, Casting units, Vanaspati oil mills, Precious and semi precious stone cutting units, Leather units and Electronics industries. The total number of registered small scale and artizen units in the city is 16799. The area wise distribution of industries is given below.

| S. No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | V. K. Industrial Area | Marbel units, Rolling mills and chemical units |
| 2. | Mansarovar | Readymade garments and printing units |
| 3. | Seetapura | Readymade garments and Gems and Jewelry units |
| 4. | Kartarpura | Powerloom factory and general industries |
| 5. | Heerawala | General industries |
| 6. | Jhotwara | Rolling units, Casting units and Vanaspati oil mills |
| 7. | Sudarshanpura | Powerloom units |
| 8. | Ghat gate area | Precious and semi precious stone cutting units |
| 9. | Nandpuri | Leather work |
| 10. | Malviya Nagar Industrial Area | Electronics and general units |

## 2.3.9 Petroleum Storage

There are four petroleum storages existing at Seetapura Industrial Area, one of each Bharat Petroleum Corporation Ltd. (BPCL), Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL) and Indo Burma Petroleum Co. Ltd. (IBPL). The total number of petrol pump of different agencies in the metropolitan city is 76. The distribution of petrol pumps is given below:

| S.No. | Petroleum Storage | No. of Outlets |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 17 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 32 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 24 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBPL) | 3 |
| | Total | 76 |

## 2.4 Bhopal

The metropolitan city of Bhopal is the capital city of the state of Madhya Pradesh. The city is located at $23^{o}$9’36” N latitude and $77^{o}$21’36”E longitude and occupies an area of about 286 $km^2$ (Fig. 5.4.1). It is the $17^{th}$ largest town in India (population wise), and the second largest in the state of Madhya Pradesh. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Bhopal is 14,54,830.

## 2.4.1 Physiography and Drainage

The Bhopal city forms a part of Malwa Plateau with generally undulating topography. A major part is covered by Vindhyan hill ranges and the valleys are occupied by Deccan trap basalts. There are several hills scattered around upper lake and the highest of them is Singarcholi near Lalghati which has an elevation of 625 m above mean sea level (msl). The elevation of Bhopal city generally varies form 490 to 601 m above msl with an average elevation of 523 m above msl. There is no river flowing through the area. The southern part is drained by river Kaliasot, a small drainage course. It is an outlet of upper lake and becomes a tributary of river Betwa in the downstream. A limited area in the western side is drained by river Kolans, Patranala.

## 2.4.2 Climate

The climate of Bhopal city is characterized by a hot summer and well distributed rainfall during the south-west monsoon season. There are three well defined seasons, the winter commences from middle of November and lasts till end of February. January is the coldest month. The summer season stretches from March to first week of June. May is the hottest month. The south-west monsoon sets in the middle of June and continues to the end of September during which the maximum rainfall occurs in the city. The temperature starts rising from the beginning of February and reaches maximum during the month of May. The maximum daily mean temperature of Bhopal City is about 40.7 °C and minimum is 26.4 °C. The summer season is the driest period of the year. The humidity is lowest (about 25%) during the month of April. On the arrival of south-west monsoon the humidity also increases. The humidity is highest during the month of August (about 88%). The humidity decreases in October due to rise in temperature and withdrawal of the monsoon. The Bhopal city is endowed with good rainfall. The normal annual rainfall of Bhopal city is about 1260 mm. The southern part of the city receives more rainfall than Northern part of the city. The rainfall decreases as we move from south to north and towards north-west. About 92% of the annual rainfall takes place during the south-west monsoon during June to September.

## 2.4.3 Geology

The area is occupied by the rocks of Vindhyan, Deccan trap and alluvial formations. On the western side of the major lineament running in NW-SE direction along Misrod valley, the basement of Deccan traps could not be met down to 118.12 m at Sarwar lying outside area of study towards south-west. However, in the eastern side of this lineament Vindhyan rocks are encountered below by a lineament. The thickness of Deccan trap was recorded to be 49.5m at Barkatullah University and it gradually decreases towards north upto the out crops of Vindhyan sandstone in Bhopal City around Anna Nagar. The Deccan traps in Misrod valley are normal infillings of pre-trappean valley by successive basaltic flows. The area formed a part of the ancient huge lake of Raja Bhoj and thus weathered basalt down to a depth of 30m is encountered in Misrod valley. The underlying Vindhyan sandstones are generally hard and compact and form an impressive base. However, in areas adjacent to hillocks the jointed sandstones underlying the weathered basalts form potential phreatic aquifer.

## 2.4.4 Potential of Ground Water

Record of ground water levels and analysis of their behaviour forms an important tool to understand hydrogeology. In order to study the behaviour of ground water levels in Bhopal city, water levels were recorded from dug wells tapping different water bearing formations in the city. The dug wells generally tap the phreatic aquifer. In the southern part of the Bhopal City the depth to water level during the pre-monsoon period varies from 4 to 6 m bgl while in the northern part it rests between 6-8, 8-10 and more than 10 m bgl. Depth to water level in the major part lying in the southern part of Bhopal city rests between 2-4 m bgl while in the area lying around Govindpura, T. T. Nagar, Anna Nagar and Chunabhatti, it lies less than 2 m bgl during the post monsoon period. The depth to water level in the same period rests between 4-6 m bgl in the extreme southern part. The water level fluctuation in the major area lies less than 4 m. The higher fluctuation in water levels is recorded in Vindhyan sandstones due to low permeability except Nabibagh area which is underlain by Deccan trap (CGWB, 2000).

In the major part of the area of study occurrence of promising aquifer zones in confined within shallow depths in 70 m. The shallow aquifer occurs in alluvium, weathered and jointed fractured portions of Deccan traps and weathered and jointed zone of Vindhyan andstone. Alluvium is deposited in patches along the major drainage with a limited yield. The Deccan trap basalt forms moderate to good shallow aquifers were thickness of weathering and vesicular zones is adequate. The Deccan traps on weathering generally develop a top layer of black cotton soil and yellow clay of low permeability. The underlying layer of weathered basalts forms the water bearing horizon tapped by most of the dug wells.

Sometimes a layer of jointed basalt located at suitable geographic locations show very high permeability and supports high pumping through dug wells. In low lying areas, the depth of weathering is greater and often a thick clay layer is also developed which confine the ground water at deeper levels. In the south-western part of Bhopal (Misrod valley) the basalt exhibits weathering up to a thickness of 30 m.

## 2.4.5 Population

As per the 2001 census, the population of metropolitan city Bhopal is 14,54,830. According to 2001 census, the literacy rate in the city was 68.8% and the participation of the male was found to be 56.7% and that of the female was 43.3%. The city has a sex ratio of 898 females for every 1000 males.

## 2.4.6 Water Supply

A quantity of 279 million liters per day (mld) water is being released from surface water sources and 23 mld through tube wells and large diameter dug wells to the customers for domestic purposes. After accounting for distribution and generation losses the net water supply from surface water sources is about 237 mld (assuming 15% loss). The total water supply available to the consumers from both surface water and ground water sources is 260 mld. The water supply to Bhopal city is available from Upper Lake and Kolar reservoir through a number of filtration plants, about 541 tube wells and a few large diameter dug wells. There are 1295 hand pumps existing in the metropolitan city of Bhopal, out of which 1095 are working. The number of overhead tanks is 16.

The demand for water supply to Bhopal city is increasing fast. The Bhopal Municipal Corporation has estimated that the water demand in the year 2015 will rise to 500-525 mld to cater the domestic needs of projected population of about 35 lakhs. To meet out this projected water demand there is a public demand to divert water of Narmada River through pipe line to Kolar reservoir.

## 2.4.7 Waste Water Generation

The rapid rate of urbanization has increased generation of waste waters, majority of which is being discharged into upper and lower lakes through various drains. The disposal of waste waters and other human activities are leading to environmental deterioration of the surface water bodies. The waste waters and domestic wastes are also being drained in existing drains which pass through municipal area and cause pollution of ground water. Besides, industrial effluents are also not properly treated and allowed to flow through the unlined drains. The water treatment plants existing in Bhopal city are as follows:

| S. No. | Location | Number | Capacity |
|---|---|---|---|
| 1. | Shimla | 2 | 4.5 MGD, 2 MGD |
| 2. | Idgah | 1 | 3.5 MGD |
| 3. | Pulpukhta | 1 | 3 MGD |
| 4. | Five MGD | 1 | 5 MGD |
| 5. | Badal Mahal | 1 | 1 MGD |
| 6. | Bairagarh | 1 | 1 MGD |

| | | | |
|---|---|---|---|
| 7. | Kolar | 1 | 34 MGD |

### 2.4.8 Status of Industries

In the metropolitan city of Bhopal, there are only two industrial areas, in which different types of small scale and cottage industries are located. Industrial areas comprises of Engineering Works, Bewerage, Bottling, Paints, Anciallary to BHEL, Electrical, Mechanical Engineering, Heavy fabrication factories, Glass fibre industries, Wooden, Saw mills, Food products, Automobiles and Agricultural equipments. The total number of registered units (small scale and cottage) in the city is 11960. The area wise distribution of industries is given below.

| S. No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Govindpura | Engineering Works, Bewerage, Bottling, Paints, Anciallary to BHEL, Electrical, Mechanical Engineering, Heavy fabrication factories, Glass fibre industries, Wooden, Saw mills, Food products and Automobiles. |
| 2. | Kaliparad | Engineering Works, Agricultural equipments |
| 3. | Habibganj Industrial Area | Anciallary to BHEL |

### 2.4.9 Petroleum Storage

There are three petroleum storages existing in Bhopal city, Hindustan Petroleum Corporation Ltd. (HPCL) and Indian Oil Corporation Ltd. (IOCL) in Nishatpura and Bharat Petroleum Corporation Ltd. (BPCL) in Bakania. The total number of petrol pump of different agencies in the metropolitan city is 50 with the following outlets:

| S.No. | Petroleum Storage | No. of Outlets |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 12 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 15 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 17 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 6 |
| | Total | 50 |

## 2.5 Indore

The metropolitan city of Indore is a commercial and industrial centre of Madhya Pradesh and lies in the heart of Malwa Plateau. The metropolitan city is located at $22^{o}26'24''$ N latitude and $75^{o}30'$E longitude and occupies an area of about 130 $km^2$ (Fig. 5.5.1). It is the $15^{th}$ largest town in India (population wise), and the largest in the state of Madhya Pradesh. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Indore is 16,39,044.

## 2.5.1 Physiography and Drainage

The Malwa plateau over which the district of Indore is situated is scarped by Vindhyan hills in the south. The average height of these hills is 579.2m. North of Vindhyan range, lies a wide, undulating plateau with scattered low flat topped hills. The plateau ranges in height 48.7 to 579.1m. The general slope of the terrain is towards north. The southern half of the district is generally rugged and hilly. The denuded Vindhyan hills follow west-south-west/east-north-east trend.

The district is drained by four tributaries of River Ganga, viz., the Chambal, the Gambhir, the Khar and the Kshipra. These rivers are generally following from south to north. The southern fringe of the district, south of Vindhyan hills, is drained by the river Narmada from flowing west to east. Except for the major rivers, most of the rivers and streams are seasonal. Floods occur during rainy season, while in the summer, the stream maintains a sluggish flow.

## 2.5.2 Climate

The climate of Indore district is characterized by hot summer and well distributed rainfall during the south west monsoon season. The year may be divided into four seasons. The winter commences from December and lasts till the end of February. The period from March to middle of June constitutes the hot weather. May is the hottest month. The south west monsoon starts from middle of June and continues till the first week of October. The average rainfall of Indore district is about 980 mm.

## 2.5.3 Geology

The area is mainly occupied by the lava flows belonging to the Deccan Trap locally known as Malwa Traps. Isolated patches of alluvium also occur along the Kshipra and Khar rivers and the Katkiya nallla. Basaltic lava flows of the Cretace-o-E ocene age are the major rock formation of the area and are known as Malwa Traps. Geological mapping of the area has brought to light a succession of five basaltic flows in an approximate vertical column of 120 m above msl. Red bole beds which are predominently the ferrugenous clays, characterised for their lithological and textural characters serves as the marker horizons in distinguishing the different flows. Individual flows differ in thickness from 15 to 30 m. Lithologically, the different types of trappean flows can be conveniently grouped as massive and vesicular basalts. The massive basalts are generally hard and compact in nature varying in colour from green to dark grey. In most of the cases they are weathered down to a depth of 3-5 metres. In the case of the vesicular basalt, the rock consists of numerous types of vesicles varying from rounded to angular and sub angular which are filled by the secondary fillings. Zeolites, silica and calcite are the common secondary minerals filling these vesicles. Structurally the trappean units are mostly horizontally disposed and do not exhibit any evidence of deformation. Vesicular units however, in individual flows with in a group of flows do not appear to occur uniformally which indicates wide variation in thickness within a short distance. The trappean rocks are often (highly) jointed but there is no uniformity in the distribution of joints and fractures. The most prominent joints in the area are those trending EW and NS and with vertical dips. At places columnar joints are conspiquousin massive basalts. Spherical weathering also is very commonly seen. The weathered product of the basalt is clayey and loomy in nature and is known as the black cotton soil which has a wide aerial extent and a variable thickness of 1.0 to 6.0 cm.

The alluvial deposits occur in narrow patches and are restricted mainly to the banks of Chambal and Gambhir rivers and their tributaries. It comprises clay, silt, gravel and sand. The sand and gravel are restricted to river channels while finer fractions are confined to river banks. These deposits attain a maximum thickness of 15 m but are very irregular in nature.

## 2.5.4 Potential of Ground Water

The interesting features of the Deccan Traps, the prevalent rock types of the district is the contrast in the nature of the water bearing properties of the different units constituting them. The massive traps with their weathered zones and fracture porosities and vesiculars traps with their minutely interconnected and partly filled vesicles play a decisive role in determining the occurrence, movement and storage of groundwater in the main water bearing horizons and invariably form potential aquifers. The zeolitic basalt in the weathered state also forms productive water bearing horizon. The red bole itself is nonproductive but it is an indicator of the presence of productive vesicular or zeolitic horizon underneath it. The well jointed massive basalts also form potential aquifers at places.

In the alluvial areas, the occurrence of groundwater is governed by sand/clay ratio. The sand and Kankar layers form fairly good water bearing layers. But these are restricted and erratic in distribution. Groundwater in the Deccan Trap basalt occurs under water table conditions within a depth range about 15 m bgl. The nature of topography, extent and depth of weathering, distribution of joints and fractures and occurrence of vesicular units govern the movement of groundwater. Further, the alternating nature of the impermeable massive and productive vesicular basalts results in groundwater occurring under confined conditions at depth. In case of confined conditions also, occurrence and movement of groundwater is governed by the hydrogeological setting, which show wide variation laterally within short distances. In alluvial materials groundwater occurs under water table conditions.

## 2.5.5 Population

As per the 2001 census, the population of Indore metropolitan city is 16,39,044. According to 2001 census, the literacy rate in the city was 71.2% and the participation of the male was found to be 57.0% and that of the female was 43.0%. The city has a sex ratio of 902 females for every 1000 males.

## 2.5.6 Water Supply

The sources of water supply in the municipal city of Indore are Narmada Project, Yashwant Sagar Reservoir, Bilawali Reservoir, tube wells and hand pumps. The supply of water from the above sources are as under:

| S. No. | Name of the source | Supply |
|---|---|---|
| 1. | Narmada Project | 32 MGD |
| 2. | Yashwant Sagar Reservoir | 3 MGD |

| | | |
|---|---|---|
| 3. | Bilawali Reservoir | 0.5 MGD |
| 4. | Tube wells, Wells, Handpumps | 5 MGD |
| | Total | 40.5 MGD |

About 88% of the supply in the metropolitan city is through surface source and 12% through ground source. 64.5% population is covered by sewerage system. The total number of tube well installed in the city is 1836, out of which 1813 are operational. The total number of hand pumps existing in the city is 460, out of which, 450 are in working condition. There are about 173 wells and bawadia in the city. The number of overhead tank existing in city is 33. Seventy percent population of the city is covered through pipeline supply.

## 2.5.7 Waste Water Generation

All the surface water sources of Indore city have water treatment plants. Fifty percent of the population is covered by sewerage system. The total solid waste produced in the city is 500 MT/day, out of which 350 MT/day is being collected by Municipal Corporation of Indore. All the waste is being collected in Devoguradiya trenching ground and is being treated.

## 2.5.8 Status of Industries

There are six industrial areas existing in the metropolitan city of Indore. Industrial areas comprises of Food product, Tobacco product, Cotton textile, Wool milk, synthetic powder, Jute product, Housary garments, Wood products, Paper and paper product, Leather and leather product, Rubber and Plastic products, Chemical and chemical product, Metal product, Basic metal industries, Machinery parts, Electric machinery product, Repairing and servicing, Steel furniture, Printing, Paints & Varnish, Pulses mills, Cold storage and Fertilizers, Electronics & Computer parts, Readymade garments, etc. The total number of registered units (small scale and cottage) in the city is 10247 (upto March 2002). The area-wise distribution of industries is given below.

| S. No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Pologround | Food product, Cotton textile, Housery garments, Wood products, Paper and paper product, Leather and leather product, Rubber and Plastic products, Chemical and chemical product, Metal product, Machinery parts, Electric machinery product, Miscellaneous manufacturing industries, Repairing and servicing, Steel furniture, Printing, Paints & Varnish, Pulses mills |
| 2. | Lakshmibai Nagar | Food product, Tobacco product, Cotton textile, Wool milk, synthetic powder, Housary garments, Wood products, Paper and paper product, Rubber and Plastic products, Chemical and chemical product, Metal product, Machinery parts, Electric machinery |

| | | |
|---|---|---|
| | | product, Miscellaneous manufacturing industries, Repairing and servicing, Steel furniture, Printing, Paints & Varnish, Pulses mills |
| 3. | Sanwer Road (Sector-6) | Food product, Tobacco product, Cotton textile, Wool milk, synthetic powder, Jute product, Housary garments, Wood products, Paper and paper product, Leather and leather product, Rubber and Plastic products, Chemical and chemical product, Metal product, Basic metal industries, Machinery parts, Electric machinery product, Miscellaneous manufacturing industries, Repairing and servicing, Steel furniture, Printing, Paints & Varnish, Pulses mills |
| 4. | Rau (Naulakha) | Chemical and chemical product, Cold storage and Fertilizers |
| 5. | Udyog Nagar | Leather and leather product, Rubber and Plastic products, Pulse mills |
| 6. | Electronics Complex, Pardeshipura | Electronics & Computer parts, Readymade garments |

## 2.5.9 Petroleum Storage

There are three petroleum storages existing on the Agra-Bombay Road out of the municipal limit of Indore city, one each of Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL) and Bharat Petroleum Corporation Ltd. (BPCL). The total number of petrol pump of different agencies in the metropolitan city is 60. The distribution of petrol pumps is given below:

| S.No. | **Petroleum Storage** | **No. of Outlets** |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 15 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 15 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 20 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 10 |
| | Total | 60 |

## 2.6 Jabalpur

The metropolitan city Jabalpur is an important city of Madhya Pradesh. The city is located at $23^{o}6'$ N latitude and $79^{o}35'24''$E longitude and occupies an area of about 131 $km^2$ (Fig. 5.6.1). It is the $27^{th}$ largest town in India (population wise), and the third largest in the state of Madhya Pradesh. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Jabalpur is 11,17,200.

## 2.6.1 Physiography and Drainage

The study area shows Nagar Haveli Plains in the north-western and western part where as the granitic rocks form a diagonal hilly belt, running in NE – SW direction for a distance of about 16 km. The granitic hills are characterised by their bouldary nature and bare vegetation can be easily distinguished from the flat – topped lameta and trap hills which occur in the eastern and south eastern part of the area. The granitic hills rise from the general level of Jabalapur city (1300 feet above msl) to height of about 1550 feet above msl. These hills occur into groups, separated by tals and plains. The south western hills group is generally known after Madan Mahal, situated at a height of 1542 feet above msl. The Madan Mahal area is nearly rounded in form and steep sides in the N-W section. It is bound by a straight nalla on the south and numerous lakes on the other sides. This area presents a rugged topography, typical of granitic region and consists of numerous tals and knolls. The NE Ghamapur part forms a belt of hills, running in an EWE-WSW direction. From the market place, Gurandi to Ranzi village for a distance of about 3 km and consists of alternating hill ranges. The most conspicious feature of the area is its bouldary nature, suggestive of the predominance of mechanical weathering mostly along the joint planes.

Geographically, the district is divided into plateau lands of Vindhyachal and Satpura in the northern and southern side, Bhitrigarh hills in the east and plains of central Katni-Mahanadi and Haveli river section. The hill ranges of Bhander, Kaimur and Satpura are parts of Vindhyachal and Satpura high lands. The mountain ranges of Vindhyachal and Satpura are 600-700 metres high whereas the hills of Bhitrigarh are 500 metres in height. The rivers Narmada, Hiran, Katni and Mahanadi are the main rivers which have formed fertile plains in the central part of the district. The main and famous river “Narmada” which enters from the adjoining district Mandla flows in the outskirts of the Jabalpur towards the eastern side and forms a world famous spot known as waterfall of ‘Bheraghat’ on the rocks of white marble which is about 24 kms from Jabalpur city. The Gour, Hiran, Niwar and Ken are the main tributaries of the river, which flows through the district and similarly other tributaries are Katni and Chhoti Mahanadi also flow towards the eastern side of the district and join into the Son river.

The Drainage pattern within the granitic region is parallel type, following the strike of the rocks and is almost E-W in Madan Mahal area and ENE-WSW in Ghamapur area. The main streams, namely Omti and Uklana nala after leaving the granitic area take N-W word turn to meet the Pariat river. Thus the drainage of the area seems to have been controlled more by Pariat river then by Narmada. Mostly talas are situated along the periphery of granitic exposures and may be due to differential erosion of granites and surrounding rocks, though at places, their formation seems to be partially due to faulting.

## 2.6.2 Climate

The area experiences a subtropical type of climate with an average minimum temperature of 18.3 °C and an average maximum of 32.1 °C. The area receives normal annual rainfall of 1130 mm with June to September being the principal rainy period.

## 2.6.3 Geology

The study area consists of the rocks of Archaen era, Bijawars, Vindhyan, Gondwanas, Lametas and Deccan traps. Schists, gneiss and granite are prevalent in the

Archaeans. The main constituents of Bijawars are dolomite, limestone and banded haematite, quartzite. Vindhyan comprises mainly of limestone, sandstone and shale. Gondwanas and lametas include chiefly limestone and sandstone. Deccan trap basalt occurs in the south and west of the district with a capping of laterite due to erosion of basalts at some places.

## 2.6.4 Potential of Ground Water

Drainage and structure affect hydrogeology of the area very closely. The granite is fine to coarse grained. Joints trending ENE-WSW and NNW-SSE with dips up to 90° are of significance. They are spaced 0.2 to 2 m apart the opening being nearly straight and upto 0.5 m in width and narrowing down with depth. Sheet joints, spaced about 0.5 m apart with dips of less than 40° are common. The joints intersect each other and are seem to depth’s of about 10 m. The depth of weathering ranges from 1-6 m maximum in low topographic area. The foliation of gneisses also attain importance. In Madan Mahal area fault running mostly E-W direction, and Ranzi Khamaria NE-SW direction play important role of ground water charging. Through alluvium downward movement of water developed weathered zone.

## 2.6.5 Population

As per the 2001 census, the population of metropolitan city Jabalpur is 11,17,200. According to 2001 census, the literacy rate in the city was 75.1% and the participation of the male was found to be 56.1% and that of the females was 43.9%. The city has a sex ratio of 898 females for every 1000 males.

## 2.6.6 Water Supply

The main sources of water supply in the metropolitan city of Jabalpur are from Pariyat, Fagua, Khandari, Gaur, Narmada River, Tube wells and hand pumps. The supply from these sources is given below:

| S. No. | Name of the Source | Supply |
|---|---|---|
| 1. | Pariyat + Fagua | 6.5 MGD |
| 2. | Khandari + Gaur | 6.5 MGD |
| 3. | Narmada River | 12 MGD |
| 4. | Tube wells + hand pumps | 5 MGD |
| | Total | 30 MGD |

A quantity of 25 MGD water is being supplied from surface water sources and only 5 MGD through tube wells and hand pumps. The total water supply available to the consumers from both surface and ground water sources is 30 MGD as against the demand of 40 MGD. There are 51,553 tap connections in the metropolitan city.

The demand of water supply to Jabalpur city is increasing fast. At present, there is a gap of 10 MGD in demand and supply. To meet out this water demand, work on the third phase of Narmada Project is going on, which is expected to be completed by March 2005. This project will provide 90 MGD extra water.

## 2.6.7 Waste Water Generation

The total solid waste generation of the city is 400 MT/day, out of which 200-250 MT/day is collected by Municipal Corporation of Jabalpur. There are landfill sites in the Kathoda gram area. The water treatment plants existing in Jabalpur city are as follows:

| S. No. | Name of the Plant | Capacity |
|---|---|---|
| 1. | Bhongadwar | 6.5 MGD |
| 2. | Ranzi | 6.5 MGD |
| 3. | Narmada Lalpur | 9 MGD<br>8.5 MGD<br>(Commissioning) |

## 2.6.8 Status of Industries

There are two industrial areas in the metropolitan city of Jabalpur with different types of small scale and cottage industries cottage. Industrial areas mainly comprises of steel fabrication factories, food products, polythene, RCC hume pipes, plastic base factories, sodium silicate, telecom, air products, etc. The total number of registered small scale and cottage units in the city is 320. The area-wise distribution of industries is given below.

| **S. No.** | **Industrial Estate/Area** | **Type of Industries** |
|---|---|---|
| 1. | Adhartal | Steel fabrication factories, Food products, Polythene, RCC hume pipes, Plastic base factories, Sodium silicate |
| 2. | Richhai | Steel fabrication factories, Food products, Polythene, RCC hume pipes, Plastic base factories, Sodium silicate, Telecom, Air products, LIMBCO. |

## 2.6.9 Petroleum Storage

There are three petroleum storages of Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL) and Bharat Petroleum Corporation Ltd. (BPCL) in Shahpura Bhitoni area. The total number of petrol pump of different agencies in the metropolitan city is 40. The distribution of petrol pumps is given below:

| **S.No.** | **Petroleum Storage** | **No. of Outlets** |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 12 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 9 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 16 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 3 |
| | Total | 40 |

## 2.7 Nagpur

The metropolitan city of Nagpur is the second capital city of Maharashtra State. The city is located at 21°5'24" N latitude and 79°5'24"E longitude and occupies an area of about 218 $km^2$ (Fig. 5.7.1). It is the 13th largest town in India (population wise), and the 3rd in the state of Maharashtra. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Nagpur is 21,22,965.

### 2.7.1 Physiography and Drainage

The city is situated at an altitude of over 290 m above sea level rising upto 350 m towards NW and SW of the city. Nag river, which is a tributary of Kanhan, takes its origin from Ambajhari and flows towards east through the city. The river water is completely polluted on account of the draining of sewage into the river. The Pili Nadi originates in the Gorewada tank and skirts the city on its northern edges. However this river was first turned into a canal and then into a nallah. Today, on the city map, one can not distinguish this river from a road, as all prominent bends have been removed by canalisation.

### 2.7.2 Climate

The metropolitan region is characterised by hot and dry summer with well distributed rainfall during the period stretching from June to September. The winter commences towards the end of November and December is normally the coldest month with mean daily temperature at 12.1°C and daily maximum temperature being 28.7 °C. From the beginning of March the temperature begin to rise sharply. May is the hottest month with mean daily maximum temperature at 42.8 °C. The relative humidity varies from 19 - 85%, however wind speed varies from 6.2-14.1 km/hr. The metropolitan region is endorsed with good rainfall with average annual rainfall being 1178.7 mm (1901-1977). The rainfall increase from Panchga, - Mahalgaon area in north - west (1050 mm) to Kalmeshwar Wakuri area,in south - east (1200 mm) direction. The assured rainfall of the area is about 910 mm per annum. There is a probability of the drought in every 5.5 year. The long term analysis of rainfall for the period 1901-1977 shows a declining trend of 1.9 mm/year, the standard deviation of rainfall is 268 mm, where as co-efficient of variation of annual rainfall is 23 %.

### 2.7.3 Geology

The crystalline rocks occupy eastern part of the region and comprise of gneisses, schists and granites. The Gondwana sediments which are represented by sandstone and shale are found in northern part of the region. The sandstone because of its granular nature possesses primary porosity and permeability and forms potential and promising aquifer in the area. The Lametas consisting of sandstones, variegated clays and cherty limestone occurs as narrow fringe from north to central part and further south west to south east of Nagpur metropolitan area. Deccan basalt occuring in western and southern parts occupies the major parts of the area in layered sequence of different lava flows and are separated by intervening red bolel green bole, inter-trappean beds. In basalt ground water occurs in weathered mantle, joints, fractures and inter flow lones. The alluvium of recent age comprising of sandi silt, clay, kankar and admixture occurs in limited extent along Kanhan and Pench rivers and as buried channels of river system.

## 2.7.4 Potential of Ground Water

The ground water occurs both under phreatic and semi confining to confining condition. The depth to water level in the pre-monsoon season ranged from 4.00 to 16.25 m bgl. The deeper water level more than 9 m during pre-monsoon period occurs around northern, north eastern and eastern parts of the region, whereas the central parts of the region except few patches (Nagpur City area) have water level less than 9 m bgl. The depth to water in post monsoon period range from 0.55 to 14.85 m bgl and water level fluctuation ranges from 0.2 to 12.0 m.

The dug wells are most common ground water extraction structure in the region and are widely used for domestic and irrigation purposes in urban and rural area. The dug wells located in Gondwana and highly weathered crystalline formation have comparatively higher yield than wells located in Massive Basalt and Lameta. The dug well constructed in hard rocks shows variation in yield from 10 to 200 $m^3$/day. The wells located in Lameta formation have extremely poor yields ($<5m^3$/day). The yield of bore wells, normally controlled by fractures, ranges from 500 to 20,000 liters per hours.

## 2.7.5 Population

As per the 2001 census, the population of metropolitan city is 21,22,965. The literacy rate in the city was 78.8% and the participation of the male was found to be 54.3% and that of the female was 45.7%. The city has a sex ratio of 934 females for every 1000 males.

## 2.7.6 Water Supply

After accounting for distribution losses due to leakages and non-domestic bulk supply, the net supply available to consumers is about 470 mld. In addition, the population in peripheral areas of Nagpur Metropolitan City in the Metropolitan Region would also have to be provided with the adequate and safe drinking water. The water supply to Nagpur City is from five surface water sources namely the Ambajhari Tank, Gorewara Tank, Kanhan River, Wunna Irrigation Tank and Pench Canal. Kanhan River is providing 155 mld while Pench Canal is providing about 366 mld of water to the city.

Besides, the Nagpur Municipal Corporation has constructed around 3181 bore wells for the supply of water. Most of the bore wells have discharge more than 500 lph. The bore wells constructed in NMC areas are not optimally utilized and are capable of yielding about 21.76 mld. The ground water utilization in Nagpur Metro City is around 7 mld. At present, the per capita water supply is around 140 lpd.

In order to optimally develop the ground water resources in the region, it is imperative to properly study and understand the ground water system of the area. Besides development it will be prudent to further augment the ground water resources through suitable recharge measures to bring in additionally to this resource.

## 2.7.7 Waste Water Generation

The total waste water generation is 360 mld. The total solid waste generation of the city is estimated to be 700 MT/day. The sewage disposal site exists in Bhandewadi. There are five water treatment plants in the city as per details given below:

| S. No. | Name of the water treatment plant | Capacity |
|---|---|---|
| 1. | Kanhan Water Treatment Plant | 108 mld |
| 2. | Pench – I | 113 mld |
| 3. | Pench – II | 133 mld |
| 4. | Pench – III | 120 mld |
| 5. | Old Gorewada | 16 mld |

## 2.7.8 Status of Industries

In the metropolitan city of Nagpur, there are four industrial areas with different types of small scale and cottage units. Industrial areas mainly comprises of Engineering Works, Saw mills, Rolling mills, Ayurvedic medicines. The area wise distribution of industries is given below.

| **S. No.** | **Industrial Estate/Area** | **Type of Industries** |
|---|---|---|
| 1. | Vanjra Industrial Area | Engineering goods, Rolling mills |
| 2. | Ghat Road Industrial Area | Rolling mills, Ayurvedic medicines, Engineering goods |
| 3. | Pardi Industrial Area | Saw mills, Engineering goods |
| 4. | Wardhaman Industrial Area | Rolling mills, Engineering goods |

## 2.7.9 Petroleum Storage

There are four petroleum storages existing in Nagpur city, one each of Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL) in the Khapri Naka area and one each of Bharat Petroleum Corporation Ltd. (BPCL) and Indo Burma Petroleum Co. Ltd. (IBPL) in Borkhedi. The total number of petrol pump of different agencies in the metropolitan city is 53. Agency wise distribution of petrol pumps is given below:

| **S.No.** | **Petroleum Storage** | **No. of Outlets** |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 11 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 17 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 20 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBPL) | 5 |
| | Total | 53 |

# 2.8 Nasik

The metropolitan city of Nasik is one of the important cities in the state of Maharashtra. The city is located at $20^{o}1'12''$ N latitude and $73^{o}30'$ E longitude and occupies an area of about 260 $km^2$ (Fig. 5.8.1). The metropolitan city is very important from the religion point of view and is called city of Gods. Nasik is associated with the prominent incidents cited in Ramayana and is the jewel in the crown of pilgrimages in India. It is the $26^{th}$ largest town in India (population wise), and the fourth largest in the state of Maharashtra. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Nasik is 11,52,048.

## 2.8.1 Physiography and Drainage

The metropolitan city of Nasik is situated in the south-west end of the country with a height of 565 m above the mean sea level. The city of Nasik is situated over nine small hills or Nav Shikhars and hence the name Nasik. The city is located on the basaltic plateau surrounded by hills in the western part but general tropography is rolling with small hillox in between. The main rivers in Nasik are Godavari, Darna, Kadwa, Mosam, Girna, Valdevi and Nasardi. The drainage of the city occurs through various small culverts and nallas and which mix into above cited rivers.

## 2.8.2 Climate

The climate of the city is salubrious perennially with rainy, winter and summer seasons. Four months (June - September) rainy season, six months (October - March) winter and three months (April - June) summer are the seasonal distribution. The summer and winter temperatures ranged 22 to 43°C and 20 to 3° C respectively. The average annual rainfall is about 700 mm. Relative humidity is maximum 62% and minimum 43.65%.

## 2.8.3 Geology

The Nasik city is occupied by Deccan basaltic rocks. The happening of weathering in these rocks is a normal process. The soil of Nasik is black with stony and loamy touch. The city contains shallow to medium black cotton soil with depth ranging from 1 to 4 m. The presence of dykes, laterites and alluvial deposites has been observed at some places.

## 2.8.4 Potential of Ground Water

As a ground water storage and movement its downward percolation is restricted due to impervious layers. However, due to basaltic terrain it has multi layer systems at a greater depth, which is limited to 90 meter. The upper ground water zone which limits up to 20 meter is subjected to periodical recharge and the aquifer cyclic storage and withdraw i.e. it is a non-confined aquifer. Ground water level fluctuates in Nasik city from 5 meter (post-monsoon) to 9 meter (pre-monsoon) below ground water level.

## 2.8.5 Population

As per the 2001 census, the population of metropolitan city Nasik is 11,52,048. According to 2001 census, the literacy rate in the city was 73.8% and the participation of the male was found to be 58.3% and that of the female was 41.7%. The city has a sex ratio of 858 females for every 1000 males.

### 2.8.6 Water Supply

Water supply to the city is through Municipal Corporation Water Works. Water supply is obtained from surface water through Gangapur Dam at Godavari river. Water is treated in Shivnagar plant and the treatment involves only primary process, which includes filtration, sedimentation and chlorination only. The drinking water supply is 278.66 MLD, which is used for domestic purpose only. The population covered by this water supply is about 90%. The need of water for industries and agriculture is being met from groundwater. About 1200 tube wells and 1370 hand pumps are present which are in operation. Besides, a large number of private hand pumps and bore wells are available which is used for domestic, agriculture and industrial purposes.

### 2.8.7 Waste Water Generation

Waste water in the city is generated from domestic and industrial activities. The waste water generated is about 98 MLD. There is no treatment plant for this waste water and it is discharged directly into various rivers. There is a Kachra depo at villori village near Nasik city. The solid waste is recycled into compost and fertilizer.

### 2.8.8 Status of Industries

Nasik is a religious city known for Triambakeshwar, a holy place on the banks of river Godavari. It is a large agriculture market for onions in the state. Security Printing Press of the government, the nation's currency printer is one of the famous set up in the city which is situated at Nasik road. Some important industries of Nasik are given below.

| S.No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Ambad Ganv Indtl. Area | Pharmaceuticals, automobiles, chemical, electronics, rubber and steel |
| 2. | Satpur | Plastic, chemical, VIP, pharmaceutical, gases and electronics |
| 3. | Saman Village | Hydro Power House |

### 2.8.9 Petroleum Storage

There are about 30 petrol pumps all over the city, which are of Bharat Petroleum Corp. Ltd. (BPCL), Indian Oil Corp. Ltd. (IOCL) and Hindustan Petroleum Corp. Ltd. (HPCL). There is no petroleum storage in the city.

## 2.9 Pune

The metropolitan city of Pune is one of the most important cities of western India in the state of Maharashtra. The city is located at 18°18'36" N latitude and 73°33' E longitude and occupies an area of about 1605 $km^2$ (Fig. 5.9.1). It is the 8th largest town in India (population wise), and the second largest in the state of Maharashtra. The population pressure on the city is ever growing. The latest census puts it in the above 1 million categories. As per the 2001 census, the population of the metropolitan city of Pune is 37,55,525.

## 2.9.1 Physiography and Drainage

The metropolitan city of Pune is situated in the south-west end of the country with a height of 560 m above the mean sea level. The city is located in the upper Bhima basin and is surrounded by hills on the east and the south. The Simhagad-Katraj-Dive ghat range is the southern boundary of the urban area. The highest point within the city is the Vetal hill (800 m) whereas the highest point of the urban area is the Simhagad fort (1400 m). Mula and Mutha are the main rivers passing through the city. Two more rivers, Pavana and Indrayani, transverses the north-western outskirts of the urban area. Mula-Mutha later empty into the Bhima river. It lies on the leeward side of the Sahyadri i.e. the Western Ghats and is hardly 50 km from the crest of the Ghat country. The drainage of the city occurs through various small culverts and nallas which mix into Mula, Mutha, Pavana and Indrayani rivers. Finally this drainage channels makes three drainage systems i.e. Bhima-Ghod, Mula-Mutha and Nira river in the Pune district.

## 2.9.2 Climate

The climate of the city is of typical monsoonal type with three distinct seasons i.e. summer, rains and winter as elsewhere in India. The height above sea level and the leeward location with reference to the Western ghats have made the city climate moderate and salubrious. The mean summer maximum and the minimum temperatures are 37º and 23º C respectively. The same for the cold season are 30 and 12ºC respectively. The evening sea breeze from west/northwest keeps the city summer nights at bearable levels. The relative humidity ranges from 36% in March to 81% in August. The average rainfall is about 70 cm in just four months from June to September.

## 2.9.3 Geology

The city is underlain by basaltic lava flows (Pahoehoe and AA) of upper cretaceous econe age associated with basic intrusives. The soil texture contains alluvial deposites of sand, gravels, fine silts and clays along the bank of major rivers. The thickness of this type of soil varies from 8 to 18 meters. The soil texture of the remaining city is made of silicates, phyllosilicates and okenite group with basalts containing dykes and laterites. The area under agriculture and grassland-scrub has decreased by 31% and 39% respectively. The area under hills and forests and water sheets remain apparently same, though there are some encroachments over some hill slopes. The urban sprawl appears to be at the cost of agriculture and grassland-scrub. The areas under settlements, agriculture, water sheets, hills and forest and grassland and scrub are 41.0, 42.1, 2.5, 7.6 and 7.0% respectively.

## 2.9.4 Potential of Ground Water

As mentioned above the Pune city is covered by a thick pile of Pahoehoe and AA flows with poor porosity. Only the porosity is developed due to weathering, cooling joints etc. and, hence, the weathering portion at the top constitutes the aquifers. Ground water occurs in the weathered and fractured zones of the basaltic formations and under semi-confined conditions. Besides, it also occurs in ground water table and phreatic conditions under the laterites and alluvial formations respectively. Normally, the ground water depth varies from place to place and ranges from 1.0 to 13.0 m. Water level fluctuation in pre- and post-monsoon periods observed was 0.28 to 11.39 m respectively.

## 2.9.5 Population

As per the 2001 census, the population of metropolitan city Pune is 37,55,525. The literacy rate in the city was 76.4% and the participation of the male was found to be 55.9% and that of the female was 44.1%. The city has a sex ratio of 896 females for every 1000 males.

## 2.9.6 Water Supply

About 90% water supply in the city is through Pune Municipal Corporation. Water source is surface, which is obtained from Mula and Mutha rivers. Water is treated at Parvati and cantonment water treatment plants and the treatment involve primary process, which includes filtration, sedimentation and chlorination only. The drinking water supply is 850.0 MLD, which is used for domestic purpose (90%) and industries (10%). The remaining need of water for industries and agriculture is being met from groundwater. About 1000 tube wells and 800 hand pumps are present which are in operation. Besides, a large number of private hand pumps and bore wells are available which is used for domestic, agriculture and industrial purposes. Pune Mahanagarpalika's routine water supply is divided into city area, Pune lashkar and kirki lashkar.

## 2.9.7 Waste Water Generation

The waste water generated in the city is due to domestic and industrial activities only. Total waste water generated is about 510 MLD. Waste water is treated by four treatment plants. These plants are Naidu Sewage Treatment Plant, Bharaioba Sewage Treatment Plant, Tanaji Sewage Treatment Plant and Bhopadi Treatment Plant. The waste water is treated through primary treatment processes such as screening, sedimentation and flocculation etc. No secondary and tertiary treatment facilities are available in these plants. These treatment plants are not sufficient for the treatment of the waste water generated. Therefore, three other treatment plants are under construction. There is one Kachra depo in the city at Hadapsar area.

## 2.9.8 Status of Industries

Pune is one of the most important Indian cities by the industries point of views. It is the home to one of the world's three largest two-wheeler manufacturers of Bajaj Auto. Other global automobiles like Telco, Mercedes Benz and Bajaj Tempo are also situated into the city. A large number of engineering, electronic and electrical industries have set up base in the large, medium and small scale sectors. The industrial township of Pimpri and Chinchwad is dotted with over 4,000 manufacturing units. This vast and well established industrial base has imbibed the city with a professional ethos and work culture. Important industries in Pune city are summarized below.

| S.No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Pimpari | Chemicals, automobiles, pharmaceuticals, electronics, rubber, steel, motors, refrigeration etc. |
| 2. | Bhoosari | Electronics, electrical, chemical, engines, paints etc. |
| 3. | Chinchwad | Plastic, chemical, pharmaceutical, printing press, home appliances, electronics, fertilizers etc. |

## 2.9.9 Petroleum Storage

There is only one petroleum storage of Hindustan Petroleum Corp. Ltd. in Pune city. About 100 petrol pumps belonging to Bharat Petroleum Corp. Ltd. (BPCL), Indian Oil Corp. Ltd. (IOCL) and Hindustan Petroleum Corp. Ltd. (HPCL) are available in the city.

## 2.10 Bangalore

The metropolitan city Bangalore is one of the fast growing cities in India. Bangalore, the capital city of Karnataka, is a major industrial and commercial centre. It occupies an area of about 1000 $km^2$ and situated in the south-eastern quadrant of the state at $12^o34'48''$ N latitude and $77^o22'48''$ E longitude at an altitude of 920 m above MSL (Fig. 5.10.1). The metropolitan city is also called the Silicon Valley of India. It is the $5^{th}$ largest town in India (population wise), and the $1^{st}$ in the state of Karnataka. As per the 2001 census, the population of the metropolitan city is 56,86,844.

## 2.10.1 Physiography and Drainage

Physiographically the district is classified into rocky upland, plateau and flat topped hills at an elevation of about 900 m. Flat topped laterite hills are seen in the northeastern part at an elevation of 900 m. The pediplains from major part of the district underlain by gneiss's and granites with the highest pediplain in the range of 850 to 950 m. Rocky upland pediplain and plateau constitute erosional topography. Major part of the pediplain is dissected by streamless flowing in southerly direction. The major part of the district lies in Cauvery basin. The major rivers draining the area are Cauvery, South Pennar, North Pennar and Polar. Cauvery along with its tributaries like Kanva, Arkavathi and Shimsha drain 67% of the area. South Polar, North Polar and Polar originate from the Nandi Hills in the northern part of the district drain 33% of the area.

## 2.10.2 Climate

The Bangalore city experiences a salubrious climate almost through out the year with the temperature ranging from 28 to 36°C during hottest months (April/May) to 16 to 25°C during winter months (December/January). The annual average rainfall is 686 mm.

Most of the rainfall is received in the south-west monsoon (June to September) period, where as considerable rainfall is received in the October month also. Apart from the above, pre-monsoon showers are very common during summer months.

## 2.10.3 Geology

Red soils and lateritic soils cover almost the entire urban areas with thin cover of alluvial soils along major stream courses and nallas. The geomorphological land forms prominently seen in the area is pediment and pediplain. Pediment is defined as undulating rock surfaces occurring at the transition zone between hills and neighboring plains dotted with rock out corps which is mainly of granites and gneisses. More over, this confirms the occurrence of poorly weathered high run-off and recharge zone. Fractures are minimal in this land form. Pediplain is a gently undulating and deeply weathered land form of coalescence of different pediments. The pediments in Bangalore metropolitan Region is mainly underlain by granites and gneisses. Further the occurrences of fractures are more significant in this zone.

## 2.10.4 Potential of Ground Water

Granites and gneisses constitute the major aquifer system in the area. Ground water occur under unconfined condition in the weathered rock and residium. The movement and occurrence of ground water is controlled by secondary porosity created by the weathering and fractures. Weathering of 2 to 25 m is commonly noticed in the area. Further, ground water occurs under semi confined condition especially in the fractured rocks which is seen below the weathered rock. Ground water development in the urban agglomeration is both by large diameter dug wells generally confining to the weathered zone and bore wells which mainly top fractured zone in. the hard rocks. These fractures some times extend very deep occurring even beyond 120 m bgl, but otherwise generally they close before 80 m depth. Generally in dug wells depth to water level varies from 5 to 20 mbgl. The dug well yields vary between 50 to 250 $m^3$/day where as the bore wells yield ranges from 142 to 518 $m^3$/day for 4 to 10 hours of pumping per day. Further, the specific capacity of the dug wells vary in the range from 13 to 100 $m^3$/day/mm/dd and in the case of bore wells the same varies from 14 to 222 $m^3$/day/m/dd (CGWB, 2000).

## 2.10.5 Population

As per 2001 census, the population of metropolitan city Bangalore is 56,86,844. The literacy rate in the city was 76.3% and the participation of the male was found to be 54.9% and that of the females was 45.1%. The city has a sex ratio of 906 females for every 1000 males.

## 2.10.6 Water Supply

The water requirement of the Bangalore metropolitan is mainly met by the surface water sources. Ground water forms only a minor part of the requirement of the city. The major sources of surface water supply (treated water) is Tippagondanahally reservoir pumping scheme. Cauvery water supply scheme, stages I, II & III. The entire water supply scheme is being maintained by the Bangalore Water Supply & Sewerage Board (BWSSB). The requirement of the Bangalore City at 140 LPCD has been worked out as 700 mld (Bangalore city population estimated as 50 lakhs). Out of this, the Thippagondanahalli tank supplies 25 mld. Cauvery stages I, II & III supply together 540 mld. Thus the total surface water supply is 565 mld. Presently there are 5500 shallow bore wells fitted with hand pumps and 757 bore wells are energized. The total estimated ground water utilization is 42.64 mld which is about 8% of the total water supply effected by BWSSB. However, there is still a gap of 92.36 mld which has to be met from other sources. There is a proposal to bring an additional 270 mld under Cauvery IV stage. Percentage of ground water to the total water supplies at present is 22%.

## 2.10.7 Waste Water Generation

The total municipal corporation waste water generation in the city is about 700 mld. About 80% of urban area is covered by underground drainage system. In other areas, people are using septic tanks and soak pits. In some places, the sewage is discharged into open drains either lined or unlined and low lying areas. There are 5 sewage treatment plants for treating waste water at Bangalore-Mysore Road (180 mld capacity), near Airport K&C Valley (163 mld capacity), Hebbal (60 mld), Madiwala (4 mld) and Kempabudhi lake (1 mld). Also, 70 mld of sewage is recycled from these plants or further utilization. Further 7 treatment plants with a total capacity of 215 mld are established and yet to be started at Krishnarajapuram, Jakkur, K&C valley, Mailsandra, Nagasandra, Kadabesanahalli and Raja canal.

The approximate solid waster generation in Bangalore city is about 2500 MT/day. The solid waste from house hold and industries is dumped in municipal waste containers located at various places in the city, door to door collection by carts and through street sweeping from where it transported to solid waste disposal sites (Landfill sites) by trucks. Ultimately, the solid waste is transported to landfill sites at Jarakkabhande kaval, Naganehalli, Krishnarajapuram, Basavanapura and KCDC at singasandra cross located outside the Bangalore municipal corporation area. There is provision for conversion of solid wastes into compost manure at KCDC singasandra cross. Recycling and segregation of solid wastes is under proposal.

## 2.10.8 Status of Industries

The metropolitan city of Bangalore is home for most fast growing industries and has a large number of multinational companies. It is also called the Silicon valley of India. Most of the Industries are located in Peenya Industrial Estate (I, II, III stage), HMT, HAL, Yelhanka, Rajajinagar, Mysore Road, Hosur Road and White field. The major industries are aircraft, earthmoving equipments, watches, garments, silk, machine tools, handicrafts, computer software, computer hardware, electronics, telecommunication, instrumentation and information technology, steel and coffee. The location and type of industrial units located in various industrial areas/estates are given below.

| S. No. | Industrial Estate/Area | Type of Industries |
|---|---|---|
| 1. | Peenya I, II, III stages | Engineering Industries, steel furnitures, Rubber and Plastic industries, garments, mouldings, electronic and |

| | | |
|---|---|---|
| | | electrical appliances, automobile components. |
| 2. | HMT | Watches and Machine tools |
| 3. | Rajajinagar | Small scale units like bolts and nuts, handicrafts |
| 4. | Yelahanka | Wheel and Axle plants, steel industries, machine tools. |
| 5. | White field | Engineering Industries, steel industries, software, machine tools |
| 6. | Mysore Road | Electrical and electronic appliances, machine tools |
| 7. | Hosur Road | Engineering industries, electrical and electronic appliances |

## 2.10.9 Petroleum Storage

There are petroleum and diesel storages existing in Whitefield (Devanagonthi), Yelhanka (IOCL, HPCL & BPCL) and Krishnarajapuram (HPCL). The oil storages are located about 15 to 30 km outside the Bangalore city area. The total number of petrol pumps of different agencies in the metropolitan city is 170 as per details given below:

| S.No. | Petroleum Storage | No.of Outlets |
|---|---|---|
| 1. | Indian Oil Corporation Ltd. (IOCL) | 60 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 40 |
| 3. | Bharat Petroleum Corporation Ltd. (BPCL) | 45 |
| 4. | Indo-Burma Petroleum Co. Ltd. (IBP) | 25 |
| | Total | 170 |

## 2.11 Hyderabad

The metropolitan city Hyderabad is the capital of Andhra Pradesh and is located at 17°12' N latitude and 78°18' E longitude (Fig. 5.11.1). Hyderabad district surrounded by nine municipalities falling in Ranga Reddy district forms the Hyderabad Urban Agglomeration with an areal extent of about 1000 $km^2$ and spreads on the North and South bank of the river Musi, a tributary of Krishna. The beautiful Hussain Sagar Lake is centrally located in the city and connecting the Hyderabad and Secunderabad twin cities. Hyderabad is a landmark of spiritual and cultural activities of Hindus and Muslims. It has beautifully planned architecture, aesthetically designed monuments, splendidly carved temples and shrines. It is $6^{th}$ largest town in India (population wise), and the first in the state of Andhra Pradesh. As per census, 2001, the population of Hyderabad metropolitan city is 55,33,640.

## 2.11.1 Physiography and Drainage

The city occupies an undulating topography with an elevation of 460 to 560 m above msl. Musi river passing through the centre of the city divides it into two parts along the South and North banks. The portion of the city on the southern bank of the city is an elongated trapezium shaped land, which consists of Mir Alam Tank, Falaknuma Hill and Saroornagar tank. The northern bank area is sub divided as Musi and Hussain sagar drainage areas. The Golkonda hill is prominent hill on this side. The general slope is towards SE. The area in general, has slope from West to East and to South. Hyderabad city is basically rest on the Granitic terrain. We can see the undulating terrain in the Hyderabad city, with big hills like Banjara Hills, Golkonda Hills, Falaknuma Hills, Moula-Ali hills etc. Even the Birla Mandir and Planetorium are located on a beautiful hillock, just opposite to the Assembly Hall in the heart of the city. The city is almost on the hard rock granitic terrain and the groundwater is available in weathered or fractured granites mostly and the people are dependent on the rain water recharge only.

The major part of the area falls in the Musi drainage basin and is drained by Musi river, which flows in almost east west direction. The drainage is mostly controlled by geology and structural pattern existing in the area. Most of the streams are ephemeral in nature. The area is divided into various such basins like Uppal subbasin, Saroornagar sub-division and miscellaneous sub-basin which join the Musi river directly. The drainage pattern in the area is semi-dendritic to rectangular type indicating poor permeability of the formation. Initially the city has.25 tanks, with the progressive urbanisation, either these tanks were disappeared or their size reduced to various human activities. The land use pattern has vastly changed over time due to rapid and progressive urbanisation. Most of the area is under residential public utility and industrial purposes. The land put to non-agricultural uses is around 94%.

### 2.11.2 Climate

The climate of the city represent distinctly dry season combined with moderate annual range of temperature. The normal rainfall of the area is 805 mm with 76% from South-West monsoon. The annual potential evapotranspiration in the area is 1757 mm. Some of the depressions originating in Bay of Bengal during post monsoon months cause wide spread heavy rains and gusty winds. The daily maximum temperature is 38.7°C in the months of May and daily minimum temperature is 13.4°C in the month of December.

### 2.11.3 Geology

Geomorphologically the area is divided into (1) Residual Hills (2) Pediment inselberg complex (3) Shallow to moderate weathered pediplains and (4) Valley hills. The thickness of weathered zone in different geomorphological units varies from 5 to 15 m. The area is underlain by oldest rocks of Archaean Group and Recent alluvium. The Archaean Group consists of pink and grey granites. The fracture system is likely to extend down to depths of 150 m below ground level in selected areas. The soils in the study area are mostly lateritic, yellow sandy clay looms and alluvial black soils. The thickness of soil cover ranges from 0.5 m in red and sandy clayey soil to about 2.0 m in alluvial black soils.

### 2.11.4 Potential of Ground water

Hyderabad urban area is underlain by rocks of Archean era and recent alluvium. Around 95% of the area is underlain by the Archean Group of rocks consisting mostly pink and grey granites. The granites occur as domes, sheets or as bouldary masses scattered over the flat or undulating topography. The alluvial formations, though negligible both in Arial extent and thickness, occur as isolated patches mainly along Musi river and other major stream courses. These formations consist of medium to coarse sands, silts and alluvial thickness varies from couple of meters to about 10 meters. The fracture system is likely to extend down to depth of 150 m below ground level in selected areas. The occurrence and movement of ground water depends on various factors like topography, landform, rainfall, geology, structure and soil etc. In Archean Crystallines (granite and gneisses) the occurrences and movement of ground water is limited to secondary porosity developed through weathering and fracturing. The thickness of weathering and intensity of fracturing vary from place to place depending upon topography, litholog and structures. Hence, the aquifers in these formations are anisotropic and non-homogenous type.

Ground water occurs under phreatic conditions in shallow weathered zone and under semi-confined to confined conditions in the fractured zones at deeper levels. The thickness of weathered zone varies from 5 to 25 m. Ground water development in the area is mostly through borewells. The depth of borewells ranges from 50 to 150 m. In places like Banjara hills etc., the borewells have been drilled up to a depth of 150m or more. It is found that the fracture system exists up to 150 m in parts of area. Therefore massive formation with fractures and joints form the potential aquifer system in the area. In alluvial area ground water occurs mostly under water table conditions in inter granular pore space. The aquifer system in alluvium is mostly of homogenous in nature. The ground water development is mostly through large diameter dug wells or dug cum bore wells with yield ranging from 3 to 5 $m^3$/day (CGWB, 2000).

## 2.11.5 Population

As per 2001 census, the population of metropolitan city Hyderabad is 55,33,640. The literacy rate in the city was 69.2% and the participation of the male was found to be 55.1% and that of the females was 44.9%. The city has a sex ratio of 938 females for every 1000 males.

## 2.11.6 Water Supply

Both Surface and ground water sources are fully utilised to meet the water needs of Hyderabad and environs. The surface water sources are Himayat Sagar, Osman Sagar, Manjira barrage and Singur dam. The total storage capacity of these surface water sources is 38.367 TMC. The total water demand of Hyderabad (urban) and environs is 1040 MLD. Out of which Hyderabad Metro Water Supply and Sewarage Board (HMWSSB) supply 660 MLD from surface water sources and 380 MLD from ground water sources. Hyderabad Metro Water Supply and Sewerage Board (HMWSSB) is supplementing surface water supply through bore wells by drawing ground water. There are 5399 numbers of 113 mm dia bore wells spread over the entire twin cities. In addition to this, majority of the residents in the city have their own bore wells to meet their complete requirement.

HMSWSSB provides safe drinking water to the resident of the city through 2.8 lakh connections. Board has around 500 public stand posts spread over twin cities. In addition Board supply water to unserved areas through mobile tankers. The total water demand of Hyderabad and environs is likely to increase to 1580 MLD and 2000 MLD by 2011 and 2021 respectively. To meet the further water demand, HMWSSB is planning to draw 410 MLD from Nagarjuna Sagar reservoir in the first phase.

The ground water resource evaluation indicates that the ground water recharge in the area is in the order of 73.3 MCM and ground water draft is estimated at 65.7

MCM. The ground water balance stands at 7.6 MCM (CGWB, 2000).

## 2.11.7 Waste Water Generation

Water treatment plant is located at Kondapur village with a treatment capacity of 45 MGD (210 MLD). The expected drawn from Akkampalli reservoir will be around 90 MGD (420 MLD). The solid waste generated in Hyderabad city is around 2800 tons per day. The STP located at Khairatabad, just adjacent to Hussain sagar is having a treatment capacity of 20 MLD. The treated water is being let into Hussain Sagar and part of it is used for watering the parks and landscapes of the Corporation. Another STP is also located near Amberpet.

## 2.11.8 Status of Industries

A large number of industries have come up in the area with a variety of products like cotton, cigarettes, refrigerators, machine tools, oil, drugs, pharmaceuticals, printing material, Mint etc. The main industrial areas are Jeedimetla, Qutubullahpur, Kathedan, Moula-Ali, Nacharam, Balanagar and Uppal etc. There are several hundreds of small scale industries in these Industrial Estates.

## 2.12 Vishakhapatnam

The metropolitan city Vishakhapatnam located on East Coast of India is one of the fastest growing industrial city in Asia. It is located at $17^{o}43'$ N latitude and $83^{o}17'$ E longitude (Fig. 5.12.1). Vishakhapatnam urban area comprises Vishakhapatnam Municipal Corporation covering 111 $km^2$ and Gajuvaka Municipality with an area of 97 $km^2$. It is the heart of the Indian Naval Defence with Eastern Naval command and Naval Scientific and Technological Laboratory. It is proud of having a natural harbour. It is $21^{st}$ largest town in India (population wise), and $2^{nd}$ in the state of Andhra Pradesh. As per census 2001, the population of Vishakhapatnam metropolitan city is 13,29,472.

## 2.12.1 Physiography and Drainage

The area has four major hill ranges viz., Kailassa, Yarada, Naraka and Kambalkonda. The rest of the area is characterized by undulating topography. The hill ranges Kailasa and Yarada running parallel to each other occur North and South of the city respectively and extend roughly in east-west direction. The area is mainly drained by rivers like Hanumanthavoka, Naravagedda, Peddagedda and numerous other minor streams taking their origin in the adjoining hills and follow general slope of the area. Besides these major streams, numerous other streams originate from local hills slopes and uplands and join the sea directly. The drainage is generally dendritic to sub-dendritic. Drainage density is more in hills and low in plains. The main course of stream, appear to be structurally controlled. A series of springs also occur in Kailasa hill range, they are perennial in nature and appear to be structurally controlled. In addition to main water bodies and reservoirs numerous/small tank exists in peripheral villages whereas in urban areas tanks might have been filled due to development activity. The important geomorphic unit of the area are hills, alluvial plains, mud flats, buried pediment, colluvial plain and coastal plain (CGWB, 2000).

## 2.12.2 Climate

The climate of the Vishakhapatnam urban area is characterized by high humidity through out the year with aggressive summer and pleasant winter. The temperature generally varies from 28 to 38°C in summer and 18 to 30°C in winter. The mean temperature ranges from 23.5 to 30°C. The mean annual rainfall of the area is 982 mm where southwest monsoon contributes about 65% of total rainfall.

## 2.12.3 Geology

The area forms a part of Eastern Ghat tectonic complex of Archaean age which include khondalites, charnockite and migmatite groups. These are overlain by laterites of subrecent age. The unconsolidated sediments of Recent age comprising red sediments, streams borne alluvium, colluvium and coastal sands also occur. The rock formations are steeply dipping with dips ranging between 60° and 80° strike and dip joints are well developed in Khondalites.

In hard rocks, the occurrence and movement of ground water is limited to secondary porosity developed through weathering and fracturing. Ground water occurs under water table conditions in weathered residuum and semi-confined to confined conditions deeper fracture zones.

## 2.12.4 Potential of Ground Water

The thickness of weathering varies from 5 m to as high as 45 m. The weathered zone is porous and thick in Khondalites compared to other rock formations except in Kaolinised zones. The mode of ground water abstraction is mostly by means of dugwells or shallow borewells and is used mostly for domestic purposes. The dug wells range in depth from 2 to 21 m, while the general depth being 8 to 10 m. The depth of borewells varies from 15 to 60m. The depth to water level ranges from 0.7 to 19.20 m. The average seasonal water level fluctuation is of the order of 1.33 to 6.39 m. The long term water levels do not show any significant trend. In hard rocks, higher yields are observed in Khondalites than in quartz – feldspathic gneisses and charnockites. It is also observed that whenever quartz veins/quartz rich intrusive occur, such wells have recorded higher yields.

In Narava tidal flat and peripheral areas ground water is not suitable for development. In areas close to Kailasa hill and Waltair high lands, water levels are deep. Exploitation is done through deep open wells and deep borewells. In area like MVP Colony, Isukathota, parts of Lawsons Bay, Mudasaralova valley ground water prospects are good. Dug wells are feasible in these zones. A preliminary assessment of ground water resource indicate that ground water recharge due to rainfall infiltration is estimated to be 16.75 MCM/Year. The ground water draft from all sources is to the tune of 16.11 MCM/ Year. The ground water recharge and draft are almost equal. However, the groundwater development is less in semi-urban areas.

## 2.12.5 Population

As per 2001 census, the population of metropolitan city Vishakhapatnam is

13,29,472. The literacy rate in the city was 69.0% and the participation of the male was found to be 55.1% and that of the females was 44.9%. The city has a sex ratio of 972 females for every 1000 males.

## 2.12.6 Water Supply

With the increased industrialization and urbanization during the last three decades there has been a lot of thrust on water resources in the urban area. Consequently there is a big gap between water supply and demand. During summer the situation becomes worse. The demand for water may further increase in future since the limits of city are expanding along with the increase in population. The principal sources of water supply in VMC are surface water and ground water. At present the water supply is around 37 MGD of which 21 MGD is utilized for drinking and domestic purpose and 16 MGD consumed by industries. The important sources of water in VMC are surface water reservoirs built across the river/streams around the city. The average per capita water supply is 19 GPCD. There is a deficit to the tune of 12 GPCD obviously the gap is met by tapping ground water. Thus, the ground water abstraction bridges the gap between demand and supply.

## 2.12.7 Status of Industries

Vishakhapatnam is very famous for industries in Andhra Pradesh, since it is having natural resources, water facility and handling facilities of many industries. It is well connected by sea, rail and air. Since it has a major Port, Vishakhapatnam has developed into a major industrial zone. Some of the major Industries of Vishakhapatnam are Hindustan Zinc Ltd, Hindustan Shipyard Ltd, Hindustan Polymers, Vishakhapatnam Steel Plant, Vishakha Refinery, Coromandal Fertlisers, Bharath Heavy Plates and Vessels, Vishakhapatnam Port Trust, Naval Dock Yard, Dredging Corporation of India etc.

## 2.13 Patna

Patna town, the capital of Bihar has got glowing historical past being capital of Great Magadh Empire during the reign of 'Ashoka the Great'. It had been a centre of trade, seat of education and rich cultural heritage. The metropolitan city is located at 25°22'12" N latitude and $85^{o}$7'48" E longitude (Fig. 5.13.1). The total geographical area of the city is 125 $km^2$. The river Punpun flows south of township limit and Ganga river is it's Northern limit. The Eastern boundary is partly with Ganga and partly with Punpun river. The Patna Canal forms its Western limit. It is $14^{th}$ largest town in India (population wise), and the first in the state of Bihar. As per census, 2001, the population of Patna metropolitan city is 17,07,429.

## 2.13.1 Physiography and Drainage

Physiographically, the township lies between the Doab region of river Punpun and Ganga, a part of which is, flood prone. This urban conglomerate falls in eastern part of Ganga plain and has got a monotonous relief with numerous localise low lying patches which occasionally gets filled in forming a pool of water during the rainy season. The general slope of the township is towards south as seen from the topographic map. The Geomorphic map prepared indicates that the township of Patna is confined to older flood plain area of Ganga river. The river Punpun flowing south of Patna and Sone flowing west of Patna overflood their bank during monsoon season, while during lean period gets dried up indicating thereby their influent character and possible high recharge to deeper aquifer.

### 2.13.2 Climate

The climate of Patna town is of tropical type and is characterized by three distinct seasons. Climatological parameter of the township presented indicates that mean maximum temperature is 31.6 °C varying between 23.6°C in January to 38.9°C in the month of May while the night temperature varies between 11 to 27.1°C with mean annual value of 20.8 °C. The relative humidity is comparatively higher over the year ranging between 41 to 83% lowest being in the month of April. The bulk of the annual rainfall (1109.8mm) is received through South Western monsoon between the period June to September.

### 2.13.3 Geology

The township and surrounding is underlain by thick fluvial sediments deposited by the river Ganga and its right bank tributaries, Sone and Punpun. Basically the deposits belong to Quaternary period and are flood plain deposits. The sediments are admixture of clay and sand of different grades.

### 2.13.4 Potential of Ground Water

Patna city lying in the alluvium formation having two major potential aquifer systems. The first shallow aquifer within depth of 50m is constituted of fine sandy horizon and second aquifer lies at depth below 50 to 70 m is of medium to coarse sand. The aquifer geometry indicates presence of clay layer at the top ranging in thickness between 30-50m, below which main potential is present consistantly over the entire area. The ground water of shallow aquifer in the area occurs under unconfined state while deeper aquifer are under semi confined to confined state. Ground water resources estimation Committee has estimated the annual ground water recharge for Patna Sadar block as 75.33 mcm besides the static ground water resources of 2500 mcm. The total ground water abstraction at present in around 181.25 mcm.

### 2.13.5 Population

As per census 2001, the population of the metropolitan city Patna is 17,07,429. The literacy rate in the city was 69.9% and the participation of the male was found to be 58.6% and that of the females was 41.4%. The city has a sex ratio of 844 females for every 1000 males.

### 2.13.6 Water Supply

With the growth of population, agricultural activity in the sub urban area has commenced; consequently the demand of water has multiplied many folds. Almost entire drinking water requirement of Patna urban area and surroundings is met through ground water. Fortunately the favourable geomorphic and hydrogeological situation of township has helped in providing sufficient supply of ground water to cater the needs of people. As per the census figures of 1991 the total population of township is 13.76 lakhs. Assuming the annual growth rate of 7.7% the estimated present population of town works out to be 22.24 lakhs. To evaluate annual drinking water need, per capita need of 200 litres per day has been assumed. The annual need of domestic water supply works out as 162.3 MCM. The per capita domestic water need has been considered slightly higher to accommodate transmission losses and wastage. The shallow aquifer is supporting the private tube wells and hand pumps over the areas. The estimated withdrawal from this aquifer is 5.5 MCM in Patna Sadar block which is quite low compared to annual recharge of 75.6 MCM. The heavy withdrawal of ground water is being done from deeper aquifer and the actual annual replenishment to this aquifer is to be identified. From the present data it is inferred that the static resource of the area is possibly being exploited.

Presently water board is operating 67 tube wells for drinking water supply of township. These tube wells are operative for 12 hours a day and total ground water abstraction through these tube wells has been estimated as 122.5MCM. It is evident that the Water Board supply of water for drinking purposes has enhanced by 15% between 1988 and 1997. The total estimated ground water utilization by other agencies in the town works out to be 58.95 MCM. Thus the total ground water abstraction at present is around 181.25 MCM.

## 2.14 Kochi

Kochi is a city with beautiful coconut palms, blue waters and a natural harbor. It is the commercial hub of Kerala (Fig. 5.14.1). Kochi is a dynamic city with soaring land prices and rapidly industrializing suburbs. The city derives its name from the Malayalam word ‘Kochazhi’ meaning small lagoon also known as ‘Queen of the Arabian Sea’. Kochi is located in the district of Ernakulam about 220 km. north of the state capital. It has an area of 2408 $km^2$. It is the $20^{th}$ largest town in India (population wise) and the largest in the state of Kerala. The population pressure on the city is ever growing. As per the 2001 census, the population of the metropolitan city of Kochi is 13,55,406.

## 2.14.1 Physiography and Drainage

Kochi contains a narrow strip of land on the south west cost of Indian sub continent bounded by the western ghats on the east. It can be divided into three main regions i.e. high, middle and low lands. High land consists of the western ghats which rise to an average of 500 ft. This region has lush plantations of tea, coffee, rubber and spices. The midlands constitute of green hills overlooking equally colorful valleys. This region is characterized by its varied and variegated cultivation of rice, coconut, arecanut, sugarcane, tapioca, ginger, banana and numerous other varieties. The low lands lie adjacent to the shoreline where fishing and coir industry thrive along with the all prevading coconut palms. The drainange system is not good in the city and the municipal corporation is working to improve the draianage system. There some culverts which carry the rain and storm water which finally mix with the Sea.

## 2.14.2 Climate

Kochi has a moderate climate with heavy showers during the months June to August due to the South-West Monsoon. The North-East Monsoon brings light rainfall during the months September, October, November and December. The annual rainfall is about 310 cm. December to February is pretty cool. In summer the temperature rises to a maximum of 40 ºC while in winter it is around 25ºC

## 2.14.3 Geology

The geology of Kochi city is classified into three deposition units, viz. eastern upper fluvial sand reach, central estuarine mud reach and western lower estuarine sand reach. The general texture of the soil also contains slits, gravel and kankar. The chemical constituents comprise silicates, quartz, alumina etc. High content of zinc in eastern sideis due to its adsorption by errous sulphide and shows tie up with montmorillonite in the central zone. Copper is found in clays and sediments, which is mainly due to reducing environment with low oxidative potential, absorption and cation exchange by clays while for western part it is mainly by fixing up of montmorillonite. Chromium is concentrated more in clays and shows gradual increase from east to west. The concentration of cadmium increases both the zones away from the central zone and maximum concentration is in the western region.

## 2.14.4 Potential of Ground Water

The metropolitan city of Kochi is situated on the southwest coast of India, which, lies just one meter above the mean level of the adjoining Arabian Sea. Western part of the city is separated from the mainland by the backwater lying within few kilometres and almost parallel to the Seashore. Water table is available with at few feet but water at most of the places is not fit for domestic use.

## 2.14.5 Population

As per census 2001, the population of the metropolitan city Kochi is 13,55,406. The literacy rate in the city was 84.5% and the participation of the male was found to be 50.4% and that of the females was 49.6%. The city has a sex ratio of 1022 females for every 1000 males.

## 2.14.6 Water Supply

The available water supply in Koch is 109 mld with 2 and 107 from ground and surface water respectively. The demand of per capita water supply is 231 lpcd. Water is supply to the houses and the industries by municipal corporation. The people percentage covered by water supply through municipal corporation is about 70. These figures are as per the survey conducted in 1994-1995. Water has to be brought from the river from the point of several kilometres upstream. Improper public water supply system and unexpected power failure always affect availability of water.

## 2.14.7 Waste Water Generation

The large amount of waste water is generated in the city due to industrial and domestic activities. Waste water is being discharged on the land, rivers and the sea resulting into the pollution of surface, ground and the sea waters; especially in the western parts of the city. Though the city has so many inter connected canals, high intensity of rainfall and unscientific design of sewage system block the water, resulting flooding and blocking the roads. Deposition of mud in the canals and careless disposal of solid wastes worsen the situation.

### 2.14.8 Status of Industries

There are many industries in the city producing various commodities. Most important units are Amalgam enterprises (shrimps crabs, squids, clam), Beta Group (cashew and other food products), Cochin Spices, Core Eco Fibres (Coir products), Interfield Laboratories (Chemicals and Agro products), Mali Chem Industries (Chemicals), Handloom, Handicrafts, Rubber, Electric, Electronic appliances, Transformers, Telephone cables, Ceramics, Tiles, Drugs, Chemicals, Paints, Newsprint, Refinery and wood craft industries. These are distributed in the city with more density in the industrial area.

### 2.14.9 Petroleum Storage

Kochi Refinery Ltd., is one of the famous sector in the petroleum production. It has several petroleum storages at its location. The petrol is distributed from here to the different petrol pump in the city. About 40 petrol pumps are located over the city, which serve the demand of people for petrol and diesel. These petrol pumps belong to Hindustan Petroleum Corporation Ltd., Indian Oil Corporation Ltd. and Bharat Petroleum Corporation Ltd.

## 2.15 AHMEDABAD

The metropolitan city Ahmedabad is the largest urban centre of Gujarat State. It is bounded by 23°02′ N latitude and 72°35′ E longitude. Ahmedabad urban agglomeration covers an area of about 300 $km^2$. of which Ahmedabad Municipal Corporation area at present is about 195 sq. km. Rapid industrial development has taken place in the northeastern (Naroda), eastern (Odhav) and southern (Vatva) fringes of the city. As per the Census handbook for 1991, the Ahmedabad Urban Agglomeration has been classified into four units i.e. Ahmedabad Municipal Corporation (AMC), Outgrowth Areas (OG), Sub-Ahmedabad Municipal Corporation, Cantonment (Cant). The municipal area is further divided into 43 wards. As per census, 2001, the population of Ahmedabad metropolitan city is 35,20,085. It is $7^{th}$ largest town in India (population wise), and the first in the state of Gujarat.

### 2.15.1 Physiography and Drainage

The area as a whole is monotonously flat and forms part of the north Gujarat alluvial plain. Surface topography is mildly undulating owing to the presence of stabilized land forms. The elevation of land surface ranges from 40 to 60 m above mean sea level with master slope towards south. The average elevation of the city area is about 48 m above mean sea level isolated high grounds, with elevations more than 60 m above mean sea level, are observed on both sides of river Sabarmati. The most important surface water body in the Ahmedabad city is the river Sabarmati. The river cuts the city into almost two parts from North to South. The water flows in the river from north to south. The area as a whole lacks surface drainage thereby causing inundation of low lying areas during monsoon period.

There are only few stream/nallas joining Sabarmati, e.g., Chandrabhaga and Duff nala. Stream chandrabhaga originating from Kali village in the north carries polluted water enroute both from domestic effluent and industrial waste water. Thus the water in river Sabarmati down stream of confluence of this stream is generally polluted. A barrage has been constructed across the Sabarmati in the southern part of Ahmedabad city near Vasna to divert the flood water of the river Sabarmati through Fatehwadi Canal System for irrigation purposes.

## 2.15.2 Climate

May is the hottest month with mean daily maximum temperature of 41.3˚C and occasionally rises up to over 46˚C. January is the coldest month with the mean daily temperature of 29˚C. The Ahmedabad city receives rainfall mainly from the south-west monsoon. The average annual rainfall for this period was 732 mm.

## 2.15.3 Geology

Geologically the area forms part of the Cambay sedimentary basin, and is underlain by post-Miocene alluvium, both aeolian and fluvial, composed of sand, silt, gravel and clay. The thickness of alluvium is estimated to be about 400 m around the city. The surfacial cover is mainly fine sand and silt of blown nature and has about 25 to 40 m thickness. Tertiary sediments underlie the alluvium and have more than 1000 m thickness.

## 2.15.4 Potential of Ground Water

Ground water in and around the city occurs both under unconfined and confined conditions in thick post-Miocene alluvium that form prolific multi-layered aquifer system in the area. One phreatic and three semi-confined aquifers occur within about 250 m depth. Unconfined aquifer, though extensive, is not being developed except in localized pockets in the outskirts where quality is not a constraint. Depth to water level ranges from less than 5 m to more than 20 m below ground level. On long term basis, water levels in this aquifer do not reflect declining trend in and around the city.

## 2.15.5 Population

As per 2001 census, the population of metropolitan city Ahmedabad is 35,20,085. According to 2001 census, the literacy rate in the city was 82.9% and the participation of the male was found to be 88.99% and that of the females was 76.09%. The city has a sex ratio of 885 females for every 1000 males.

## 2.15.6 Water Supply

Rapid urbanization and industrialization have increased in demand of water for domestic as well as industrial requirements. The main source of water supply for the Ahmedabad Municipal Corporation Area is (1) the surface water of the Sabarmati river pumped through 16 infiltration wells located in river bed at Dudheshwar, raw water from Zinger pumphouse and 7 French Wells located at Kotarpur, Bhadreshwar, Camp Hanuman (Sadar Bazar), Achchair and Sabarmati Railway bridge, Motara and Dudheshwar Water

Works (2) 380 tubewells isolated tubewells located all over the city.

## 2.15.7 Waste Water Generation

The main causes of pollution of ground water in Ahmedabad are the sewage- and industrial effluent. Shallow aquifer in the area is most vulnerable to ground water pollution particularly in the areas where water levels are at shallow depths. Presently only one third of the sewage of the city is being partially treated. There are only two sewage treatment plants located at Vasna and Pirana with capacity of 12 and 72 MGD respectively. Part of the treated water is recycled and used for irrigation and industrial purposes and the excess quantity is discharged in the Sabarmati river. Remaining two thirds of untreated sewage is directly discharged in the Sabarmati.

Some parts of the city, particularly the sub-urban areas, lack sewage disposal facilities. The household refuge is normally disposed off in septic tanks constructed for individual houses. The seepage from these septic tanks and from the Sabarmati river make the phreatic aquifer highly vulnerable to pollution. Other likely sources of pollution are underground leakage, choking and overflowing of sewers, few localised land fill areas and polluted surface water in river.

The municipal solid waste generated is about 2100 tonnes per day, out of which 500 tonnes per day is being treated by one of the treatment plant located at Sewage Farm site, Pirana road. The disposal site for dumping solid waste is also located at Pirana road.

## 2.15.8 Status of Industries

The principal industrial estates within Ahmedabad Urban areas are Odhav, Vatva and Naroda. Several small and medium industries are in Narol area also. All these industrial areas are located in the eastern part of Ahmedabad. The industrial effluent from these areas are either discharged into the Kharicut canal, small nallas or spread over the topographic depressions. This has caused degradation of land in these areas and probably also effected the shallow ground water. The State Govt. has taken serious view of this problem and directed all the industries to treat the effluent before discharging in the Kharicut canal, however, these measures are not being taken. The total number of industries registered is 64352. The details of industries existing in these industrial areas are as under:

| S. No. | Industrial Estate/Area | Type of industries |
|---|---|---|
| 1. | Vatva | Pharmaceutical, Chemical |
| 2. | Odhav | Powerloom, Oil industries |
| 3. | Naroda | Chemical, Electronic, Electric motors |

## 2.15.9 Petroleum Storage

There are two petroleum storages existing in Ahmedabad city. One each of Hindustan Petroleum Corporation Ltd. (HPCL) in Chandola Talab, Naroda road and Indian Oil Corporation Ltd. (IOCL) in Sabarmati, Chandkheda. The total number of petrol pump of different agencies in the metropolitan city is 131. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 38 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 32 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 45 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 16 |
| | Total | 131 |

# 2.16 RAJKOT

The metropolitan city Rajkot is one of the most important commercial and industrial cities of Saurashtra. It is bounded by 22°18′ N latitude and 70°47′ E longitude. The town of Rajkot occupies the central position in the Saurastra peninsula. The 400 years old settlement is situated on the main link railway Hyderabad - Rajkot - Jamnagar. As a result of its locational advantage, this town has achieved a prominent place in the economic development of the region. Rajkot urban agglomeration covers an area of about 104.86 $km^2$. Rajkot Municipal Corporation (RMC) has reconstituted its wards and the boundaries of wards reconstructed into 24 new wards. As per census, 2001, the population of Rajkot metropolitan city is 10,02,160. It is $35^{th}$ largest town in India (population wise), and the fouth in the state of Gujarat.

## 2.16.1 Physiography and Drainage

The city of Rajkot lies in the central part of Gujarat peninsula of Saurashtra and at an elevation of 133 m above mean sea level. The city has a diverse landscape made up of plateau, hills, linear ridges and alluvial plains. The southern and western parts of the district are primarily covered by Deccan Traps, characterized by undulating topography with the presence of plateaus at some locations. In the northern part, topography is plain with gentle slope towards north and west. The east west trending linear ridge forming upland south of Rajkot forms water divide for south and southwesterly flowing drainage basin of Bhadar and north and northeasterly flowing drainage basins of Aji, Machhu etc. The general topography of RMC is almost plain with a gentle slope from 120 m to 139 m from south east to north-west. The land is undulating in the north-west of the town. The drainage network of Rajkot district is mainly controlled by Bhadar, Machhu, Aji rivers and their tributaries. The city of Rajkot is situated along the Aji River, which is also ephemeral in nature. The main tributary of Aji is Nyari, located at southwest side of Rajkot city. There are two natural water reservoir (lakes) located near Rajkot city viz; Lalpari and Randera, at the distance of 4 km and 6 km respectively from the city. Artificial water reservoirs (dams) are located very near to the city, Aji I dam is built at a distance of 9 kms from Rajkot city and Aji II at a distance of 15 kms. In addition to this, there are a number of nallahs and low lying areas located in RMC area which direct the drainage flow in the city area.

## 2.16.2 Climate

The climate of the city is hot and dry. The average maximum and minimum temperatures recorded over the last 40 years are 43.5˚C and 24.2˚C respectively. The Rajkot city receives rainfall mainly from the south-west monsoon. The average annual rainfall is observed about 500 mm in the area.

## 2.16.3 Geology

The geological investigations of Rajkot district has revealed that the area is mainly constituted of Dharangadhra sand stones (Upper Jurassic to Lower Cretaceous), Deccan Trap (Upper Cretaceous to Lower Eocene), Fluviomarine alluvium and Milliolite limestone (Quaternary to Upper Tertiary). However, major part of the area is constituted of Basaltic lava flows.

## 2.16.4 Potential of Ground Water

The soil in the Rajkot region is underlain with the igneous rocks of the Deccan Trap. This rock as such has no inter-granular porosity. The original inter crystal spaces, small cavities and inclusions within some of the small crystal spaces, small cavities and inclusions within some of very small and unimportant with respect to water availability. The coarse grained rocks that are common in the region are more permeable than fine grained rocks. The depth of weathering ranges from 2.0 m to 15.0 m. However, along the Nyari River and the Aji the depth of weathered rock goes down even upto 100 m below ground level. Water also occurs in the zone of vesicular and fragmented material between the various rock layers. This rock is generally transversed by large openings that take in surface water rapidly.

## 2.16.5 Population

As per 2001 census, the population of metropolitan city Rajkot is 10,02,160. According to 2001 census, the literacy rate in the city was 73.86% and the participation of the male was found to be 55.47% and that of the females was 44.53%. The city has a sex ratio of 906 females for every 1000 males.

## 2.16.6 Water Supply

The availability of water is arguably the greatest long term problem facing Rajkot. The city lies in a water deficit region; rains are irregular and there is no perennial source of water. Since the city lies in a hard rock area the availability of groundwater is limited. The Rajkot Municipal Corporation (RMC) is making great efforts to provide water supply to the citizens. RMC is drawing water from various sources viz; Bhadar, Aji-I, Nyari-I, Nyari-II, Lalpari and Randarda Lake and from Narmada Canal based pipeline. RMC is getting 27.24 MLD from Aji-I with twine lake of Lalpari and Randarda water supply scheme, 31.78 MLD from Nyari-I water supply scheme, 45 MLD from each of Bhadar and Nyari-II water supply scheme and presently as a temporary measure Government of Gujarat have planned to supply 75 MLD of quantity to Rajkot from the section-Maliya Jamnagar.

The requirement of the water per capita is being considered 120 LPCD. With this, the present requirement of the city is 105 MLD. Considering 28% system losses the gross requirement works out to 135 MLD which is optimal availability of water from all the reservoirs during good rainfall year. However, during the scarcity condition the city supply is being curtailed up to 90 LPCD depending upon the availability of water from the all the reservoirs. Rajkot Municipal Corporation (RMC) supplies water to domestic consumers through piped individuals tap connections in older Rajkot, through tankers and stand posts in recently merged area and through community stand post in slum and backward area. 185000 house connections, 1150 stand posts, 1700 handpumps and 250 tankers are provided by RMC to cater the need of the people. In normal conditions, RMC supplies water 110 LPCD.

## 2.16.7 Waste Water Generation

The treatment of water is carried out at Ribda, Aji, Nyari, and Ghanteshwar. Ribda Filter Plant, which is about 25 km away from the city, has 50 MLD design capacity. Aji Filter Plant is located near Aji dam site, has two water treatment plants with total design capacity of 103 MLD. Nyari Filter Plant is within the city, has one water treatment plant of 32 MLD design capacity. Filter Plant at Ghanteshwar which is located near the city out skirt, has water treatment design capacity of 14 MLD. These all sum to have water treatment capacity of 199 MLD against total city supply of 140 MLD. This shows about 1.5 times more filtering capacity.

Rajkot Municipal Corporation with financial assistance from World Bank, an underground sewerage project was implemented and the said project was commissioned in the year 1994. The sewage being pumped to the sewage treatment plant for the treatment, the capacity of the plant is 44.5 MLD, however it is inadequate to cater the present quantity of sewage about 64 MLD and as such RMC has decided to enhance the capacity of the existing sewage treatment plant by 44.5 MLD. Total solid waste generation of the city is about 350 MT/day, out of which 300 MT/day is being treated by Solid Waste Department of Rajkot Municipal Corporation. The site for disposal of waste i.e. landfill site is in Nakarawadi.

## 2.16.8 Status of Industries

Rajkot is a town of comparatively recent growth. Like many other cities it has developed from a small hamlet to a prosperous town of today. The industrial development in the city started with the establishment of the first textile mill in the region towards the end of 1910. There are eight industrial areas/estates functioning in the city. The total number of small scale industries registered is about 12000. The details of industries existing in these industrial areas are as under:

| **S. No.** | **Industrial Estate/Area** | **Type of industries** |
|---|---|---|
| 1. | Bhaktinagar | Engineering works, Diesel engineering |
| 2. | Bhaktinagar Estate | Engineering works |
| 3. | Mavdi Plot | Electric motors, Foundaries, Machine tools |
| 4. | Umakant Pandit Udyognagar | Engineering works |
| 5. | Atika Industrial Area | Foundaries, Forging, Machine tools |
| 6. | Aji Industrial Estate | Engineering works |
| 7. | Patelnagar Sorathiyawadi Area | Engineering works, Foundaries, Machine tools |
| 8. | Latiplot (Ranchhodnagar) | Textiles |

## 2.16.9 Petroleum storage

There are three petroleum storages existing in Rajkot city. One each of Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL) and Bharat Petroleum Corporation Ltd. (BPCL) existing in Madhapar on Jamnagar Octroi Naka Road. The total number of petrol pump of different agencies in the metropolitan city is 35. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 8 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 9 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 13 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 5 |
| | Total | 35 |

## 2.17 SURAT

The metropolitan city Surat is the ancient port city of Gujarat State. It is bounded by 21°10′ N latitude and 72°50′ E longitude. Surat urban agglomeration covers an area of about 334 $km^2$. The city is situated on the left bank of the Tapti River, 14 miles from its mouth. A moat indicates the dividing-line between the old city, with its narrow streets and handsome houses, and the newer suburbs, but the city wall has almost disappeared. The city is largely recognized for its textile and diamond businesses. 92% of the world's diamonds are cut and polished in Surat, thus it has been called the "Diamond capital of the world". It is also the fastest growing city in the world as per U N Survey. Rapid industrial development has taken place in the city. The municipal area is further divided into 34 wards. Surat is now India's second cleanest city. Surat was ranked the No.1 city in India to earn, invest and live. Surat has the highest No. of flyovers in Gujarat. As per census, 2001, the population of Surat metropolitan city is 28,11,466. It is $9^{th}$ largest town in India (population wise), and the second in the state of Gujarat.

### 2.17.1 Physiography and Drainage

Surat is a port city situated on the banks of the Tapti river (though the port has disappeared because of the damming of the river Tapti), the nearest port is now in Hazira which falls in the metropolitan area of Surat. The city has an average elevation of 13 m. The Surat district is surrounded by Bharuch, Narmada (North), Navsari and Dang (South) districts. To the west is the Gulf of Cambay.

### 2.17.2 Climate

The climate of the metropolitan city is moderate tropical type. In winter, the temperature of the city varies from 12˚C to 31˚C, while it varies from 24˚C to 42˚C in summer season. The Surat city receives rainfall mainly from the south-west monsoon (i.e. from mid June to mid September). The average annual rainfall for this period is recorded to be 931 mm.

### 2.17.3 Geology

The soil of the area is of black cotton type upto 1.5 m followed by yellow soil and silt upto 10 m. Below 10 m depth, soft rocks are available. There is no signature of hardrock in the area.

### 2.17.4 Potential of Ground Water

The area is occupied by the Deccan Trap lava flows of Upper Cretaceous to Lower Eocene age. The lava flows consist of basalt, usually massive, fine grained, greenish to grayish black in colour. The basalt is generally massive in the lower portion of the flow and upper part is generally vesicular. Because of absence of any marker horizon and limited lateral extension of the flow units, the flow can be identified by vesicles and their physical features. The vesicles are filled with zeolites, calcite and secondary silica. The basalt is generally altered to grayish and reddish brown colour at the contact of flows. The thickness of Deccan trap is more than 200 m in the study area. Fractured basalt and flow contacts are water yielding zones.

## 2.17.5 Population

As per 2001 census, the population of metropolitan city Surat is 28,11,466. According to 2001 census, the literacy rate in the city was 72.04% and the participation of the male was found to be 60.70% and that of the females was 39.30%. The city has a sex ratio of 647 females for every 1000 males.

## 2.17.6 Water Supply

The water demand of the metropolitan city Surat is estimated to be 450 MLD which is fulfilled by twelve pumping stations operating in the city.

## 2.17.7 Waste Water Generation

There is approximately 560 MLD waste water generation in the metropolitan city. Six waste water treatment plants located at Aanzana, Bhesan, Bamrouli, Bhattar, Karaneh and Singunpur are treating waste water of the city. The municipal solid waste generated is about 1000 metric tonnes per day, out of which 98% is being collected and disposed off. The disposal site for collection of solid waste is located at village Bhesan and Aanzana. Finally it is disposed off at Khajod Sachin.

## 2.17.8 Status of Industries

Surat is also an industrial hub for the production of synthetic fibers and man-made fabrics, contributing almost 28% of India's total synthetic fiber output and 40% of the nation's total man-made fabric production and computrised embroidery work. Surat is at the heart of India's thriving diamond-polishing industry, which in 2005 cut 92% of the world's diamond pieces and earned India $8 billion in exports. In addition it is home to several major processing facilities/manufacturing centers for Reliance Petrochemicals, Essar Steel, Larsen & Toubro, KRIBHCO, ONGC, Shell, and many others. The principal industrial areas within Surat Urban areas are at Pandesara, Sachin-Udena, Khatra, Udna Mangala and Varacha. The total number of industries registered is about 45000. The details of industries existing in these industrial areas are as under:

| S. No. | Industrial Estate/Area | Type of industries |
|---|---|---|
| 1. | Pandesara | Textile, Chemical dying and Printing |

| | | |
|---|---|---|
| 2. | Sachin-Udena | Textile |
| 3. | Khatodara | Chemical dying and Printing |
| 4. | Udna Mangala | Copper and Textile |
| 5. | Varacha | Diamond |

## 2.17.9 Petroleum Storage

There are petroleum storage depot of Bharat Petroleum Corporation Ltd., Hindustan Petroleum Corporation Ltd., Indian Oil Corporation Ltd. and Indo Burma Petroleum Co. Ltd. at Hazira. There are about 51 petrol pumps existing in the city. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 17 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 12 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 14 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 8 |
| | Total | 51 |

## 2.18 VADODARA

The metropolitan city Vadodara is the graceful city of Gujarat State. It is bounded by 22°18′ N latitude and 73°16′ E longitude. Vadodara urban agglomeration covers an area of about 140 $km^2$. Rapid industrial development has taken place in the city. The municipal area is further divided into 28 wards. As per census, 2001, the population of Vadodara metropolitan city is 14,92,398. It is $16^{th}$ largest town in India (population wise), and the third in the state of Gujarat.

## 2.18.1 Physiography and Drainage

Vadodara district forms a part of the great Gujarat plain. The eastern portion of the district comprising the Chhota Udepur, the Kavant, the Jambughoda and the Naswadi Taluka is hilly while rest of the district, the western and southern part, comprising of Mahi and Narmada Doab, is a level plain and undulating terrain. The eastern part of the district, with several ridges, plateaus and isolated hills have elevation in range of 90 to 481 m above mean sea level. The most of the western part, comprising of Mahi – Narmada Doab, is more or less level plain. There are some linear tracts, along Mahi, Viswamitre and Dhadhar rivers, have ravine landforms.

The Narmada and the Mahi are the chief rivers of the district. Although they flow along the northwestern and southern boundary respectively, the entire district, as a River Basin, is divided into these two, the Narmada and the Mahi Basin. The Mesari, the Goma and the Karad are the small rivers flowing northwest part of the district, are tributaries of Mahi River, and are part of Mahi Basin. The Jambuva, the Surya, the Viswamitre and the Dhadhar, which flow through central part of the district and empty into Gulf of Khambat, are also part of Mahi Basin. The eastern and the southern part of the district, drained by the Narmada river and its tributaries, like the Unch, the Heran, the Dev, the Orsang, the Karjan, the Aswan and the Bhukhi, constitutes Narmada basin.

## 2.18.2 Climate

The climate of the metropolitan city is moderate tropical type. The temperature of the city varies from 8˚C to 46˚C. The Vadodara city receives rainfall mainly from the south-west monsoon. The average annual rainfall for this period is recorded as 900 mm.

## 2.18.3 Geology

The earliest geological evolution of the basement rocks, exposed in northern and eastern parts, had been controlled by the Precambrian orogenies (Arvalli and Delhi cycles), and the older crystalline rocks ideally shows folds, faults and magmatism related to the two orogenies. After Precambrian orogenies, major geological events of Vadodara district were confined to Mesozoic and Cenozoic Eras which can be related with the breaking up of the Gondwana land and the subsequent northward drift of the Indian sub-continent, involving formation of sediments and Deccan Trap Volcanism with uplifts and subsidence along the two major lineaments – Narmada and Cambay rift system. The cretaceous and Tertiary sedimentary basins were faults controlled and manifest the tectonism related to the two major features, Narmada and Cambay rift system.

## 2.18.4 Potential of Ground Water

Groundwater occurs as unconfined to confined conditions, depending depth and disposition of the aquifer units. In fringe areas of Savli, Vaghoriya and Vadodara in north & central part of the district, thickness of alluvium is less, few meters to 40 m, at such places groundwater invariably occurs in unconfined conditions but have variable groundwater quality. In areas where alluvium is underlain by Tertiary sediments, around southeast & north west of Vadodara city, quality is brackish to saline. In Narmada –Mahi Doab, thickness of the alluvium increases towards west to 70 m at Tentalao, 85 m at Padra and 150 m at Vagra (Bharuch District), it reduces in the north –eastern sector to 13-45 m around Alamgir, Akot, Chatral and Palaswada. In former area ground water occurs in confined conditions while at latter places it is in phreatic to semi confined condition. In shallow alluvium deposits, such as riverbed, river terraces or floodplains on banks of Mahi, Narmada Orsang etc., unconfined condition is common. A distinct physiographic unit of alluvium area, ravine topography areas along meandering course of Mahi, Viswamitri, Dhadhar & Orsang, have relatively deep water level, few meter below bed levels of the dry river bed.

## 2.18.5 Population

As per 2001 census, the population of metropolitan city Vadodara is 14,92,398. According to 2001 census, the literacy rate in the city was 77.53% and the participation of the male was found to be 55.20% and that of the females was 44.80%. The city has a sex ratio of 812 females for every 1000 males.

## 2.18.6 Water Supply

The water demand of the metropolitan city Vadodara is estimated to be 290 MLD. Mostly, the demand is fulfilled by Mahi Sagar after treatment at Nimeta near Azwa and partially by ground water.

## 2.18.7 Waste Water Generation

There is 215 MLD waste water generation in the metropolitan city. Two waste water treatment plants located at Nimeta and Azwa are treating waste water of the city. The municipal solid waste generated is about 510 metric tonnes per day, out of which 460 metric tonnes per day is being collected and disposed off. The disposal site for dumping solid waste is also located at Varsa.

## 2.18.8 Status of Industries

The principal industrial areas within Vadodara Urban areas are at Makarpura and Nandisari. The total number of industries registered is about 7500, out of which 6000 are functioning. There are about 2200 industries under GIDC in Makarpura. The details of industries existing in these industrial areas are as under:

| S. No. | Industrial Estate/Area | Type of industries |
|---|---|---|
| 1. | Makarpura | Engineering goods, Pharmaceutical |
| 2. | Nandisari | Fabrication, electronics, electrical, heavy machine and light machine engineering, Pharmaceutical |

## 2.18.9 Petroleum storage

There are petroleum storage depot of Bharat Petroleum Corporation Ltd., Hindustan Petroleum Corporation Ltd., Indian Oil Corporation Ltd. and Indo Burma Petroleum Co. Ltd. at Koyali, Nandeshwari, Dumad and Dumad (Asoj) respectively. There are about 34 petrol pumps existing in the city. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 6 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 11 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 15 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 2 |
| | Total | 34 |

# 2.19 ASANSOL

The metropolitan city Asansol, a coal-mining-industrial centre, is the second largest city in West Bengal, after Kolkata. It is a sub-division located in Bardhaman District, in the western periphery of the state. It occupies an area of 127.237 $km^2$. It is bounded by 23°41′ N latitude and 86°59′ N E longitude. The municipal corporation has divided the city into 50 wards. As per census, 2001, the population of Asansol metropolitan city is 10,90,171. It is $29^{th}$ largest town in India (population wise), and the second in the state of West Bengal.

## 2.19.1 Physiography and Drainage

Asansol is in the heart of the coal country. Ranigunj Coalfields covers an area of 1530 sq km. Although it is spread over four districts of West Bengal – Bardhaman, Birbhum, Bankura and Purulia – and a part of Dhanbad district (Jharia coalfields are also in that district) of Jharkhand, the heart of Ranigunj Coalfields lies in the Asansol region.Asansol is situated at an average elevation of 97 metres.While most of Bengal is flat alluvial plains, Asansol subdivision lies on exposed Gondwana rocks and consists mostly of undulating laterite soil. It forms the lower edge of the Chota Nagpur plateau, which occupies most of Jharkhand. It is located between two mighty rivers, Damodar and Ajay. Another mighty river, Barakar, joins the Damodar near Dishergarh. A small rivulet, Nunia, flows past Asansol. The Ghagarburi temple on its banks attracts devotees round the year. While Dhanbad district lies on the western side, Durgapur sub division of Bardhman district lies on the eastern side. To the south, across the Damodar river are the Purulia and Bankura districts. To the north are Dumka and Birbhum districts. Dhanbad district across the Barakar river in Jharkhand is also a major mining area and has close links with Asansol. Both lie in the Damodar valley.

## 2.19.2 Climate

The climate of the Asansol district is dry and hot in summer and dry and cold in winter with an intermediate monsoon period from the middle of June to the end of September. The summer is extremely hot, whereas the winters from November to February are very pleasant with temperature varying 8˚C to 34˚C. After February, the climate becomes warmer till the rains break in the middle of June. The temperature during these four months from March to June usually varies from 13˚C to 45.5˚C. During the remaining months, July to October, which include the rainy season, temperature usually ranges from 15˚C to 36˚C. Average rainfall of the area is 1310.6 mm, most of which is precipitated during the monsoon months.

## 2.19.3 Geology

The geology of the area belongs to the Gondwanas which are overlained by alluvial soil and laterite. The entire area is almost covered by thick layer of soil, alluvium, laterite etc. Below this occur the rocks of the Raniganj formation of lower Gondwanas which mainly comprises of sandstones of varying grain size, grey shales, intercalation of shale and sandstones along with coal seam. The underground mine area is structurally affected by as many as 4 faults, out of which two faults are major ones with throw varying from 20 to 70 m and the remaining two are minor faults. The buffer zone is occupied by mostly alluvium, sandy soil, lateritic clay and gravel followed by Raniganj formation. The occurrence of alluvial soil is widely spreaded in the area with considerable thickness ranging from 3 to 20 m.

## 2.19.4 Potential of Ground Water

Top aquifers consist of mostly detrital mantle comprising of alluvium, sandy soil, lateritic clay and gravel together with partly consolidated weathered sandstones. From boreholes logs and depth of open wells taping aquifer, it can be seen that the thickness of top aquifer ranges from 3 m to 20 m. Ground water occurs in this formation under the water table conditions. The water levels in existing open wells ranges from 2.1 to 16.5 m and 6.7 to 9.0 m below ground level in pre and post-monsoon respectively. The fluctuation of water table is 6.1 m. The ground water flow direction is towards south-east i.e. towards Damodar river with hydraulic gradient of 0.01 to 0.008 while it has been also inferred to be towards Damodar river in the buffer zone which controls the master drainage of the area. The average fluctuation in water levels between the two extreme seasons is around 6.1 m in the area. In respect of the confined/semiconfined aquifer in the core zone area, the piezometric head is at deeper level in relation to potentiometric levels of dug wells tapping the unconfined aquifer inferring hydrological discontinuity or low pressure head in deep aquifers.

## 2.19.5 Population

As per 2001 census, the population of Asansol metropolitan city is 10,64,357. According to 2001 census, the literacy rate in the city was 64.94% and the participation of the male was found to be 61.3% and that of the females was 38.7%. The city has a sex ratio of 834 females for every 1000 males.

## 2.19.6 Water Supply

The main source of water supply in Asansol city is Damodar river and Barakar river. The water demand of the city is estimated to be 15 MGD. To fulfil this demand, about 9.82 MGD is supplied by the Asansol Municipal Corporation of which 5 MGD through subsurface (i.e. radial collector wells in Damodar river), 1.5 MGD from Damodar river and 3.32 MGD from Barakar river. Apart from this, 500 handpumps and 200 dugwells are provided by Asansol Municipal Corporation.

## 2.19.7 Waste Water Generation

The water treatment plant at Damodar is located at Kalajharia with design capacity of 2 MGD and 3 MGD respectively. Total solid waste generation of the city is about 180 MT/day. Treatment of the waste is being done by low land filling using Vermi Composit method. The landfill site is located in Matkuria.

## 2.19.8 Status of Industries

Being the central city for the coal belt, Asansol is heavily industrialized though many of the industries have fallen on hard times in recent years, leading to its transformation into a trading town that utilizes its position as the transport centre.The major industries in the study area are Eastern Coalfields (a subsidiary of Coal India Limited), IISCO Steel Plant of Steel Authority of India Limited, Chittaranjan Locomotive Works, Hindustan Cables Ltd., Disergarh Power Supply, Damodar Valley Corporation (DVC), Burn

Standard, Reckitt and Coleman, couple of cement plants, such as Burnpur Cement, and quite a few refractory units;such as Kabita Refractories. The industrial growth that has taken place since the opening up of the Indian economy in 1991 is yet to make an impact on the Asansol industrial region. However, with the continued good performance and development of Chittaranjan Locomotive Works, extensive activities of Eastern Coalfields, and the sanction of major investment for the modernisation of the IISCO Steel Plant of SAIL, things have started looking up again. Pandaveswar, Kajora, Jhanjra Bankola, Kenda, Sonepur, Kunustoria, Satgram, Sripur, Sodepur and Salanpur are the major coal areas around Asansol. The main industrial estate in metropolitan city of Asansol is Kanyapur industrial estate under Asansol-Durgapur Development Authority (ADDA). It includes polymer industries, cement, plastic, musturd oil, rubber, leather products, polymer pipes, fabrication, paint and varnish, flour mills, PVC pipes, aromatic chemicals, food product packing etc. The total number of small scale industries registered is about 500.

### 2.19.9 Petroleum storage

There is one petrol pumping station of Indian Oil Corporation Ltd. (IOCL), in Kalla. The storage depot of petroleum exists in Rajban and Durgapur. The total number of petrol pump of different agencies in the metropolitan city is 12. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 3 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 4 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 3 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 2 |
| | Total | 12 |

## 2.20 DHANBAD

The metropolitan city Dhanbad is the city of newly built Jharkhand state. It occupies an area of 355.77 $km^2$. It is bounded by 23°48′ N latitude and 86°27′ E longitude. It is the district headquarter and famous for its coal mines and industrial establishments; because of this, it has been called the "Coal Capital" of India and the “City of Coal”. Hazaribagh and Santhal Parganas districts lie to its north and northeast and Puruliya and Barddhaman districts to the south and east respectively. Barakar river forms the natural northern and eastern boundaries whereas Damodar river dissecting the district almost into two halves forms part its southern boundaries. The headquater of Dhanbad town situated in the central part of the district and is connected to Calcutta by the Grand Chord section of the Eastern Railway. The district has two subdivisions, viz; the Sadar and Baghmara. The municipal corporation has divided the city into 32 wards. As per census, 2001, the population of Dhanbad metropolitan city is 10,64,357. It is $30^{th}$ largest town in India (population wise), and the second in the state of Jharkhand.

### 2.20.1 Physiography and Drainage

The study area is a part of the Chotanagpur plateau but it is more of upland in the northern part. There are no large stretches in the district which may be called plains; the areas around Chas and Chandankiary are low upland, where cultivation is practised. The northern fringe of the district, north of G T Road is hilly. The Parashnath hill, just outside the notheastern boundary of the district is a landmark with altitude of 1366 m. Broadly speaking, the southern portion of the district consists of colliery area with industrial towns while the northern portion comprises the area of hills and scattered villages.

Damodar is the most important river with an easterly course for about 125 km within the district. On its entry into the district it receives the Jamuna river, a stream which marks the boundary between Hazaribagh and Dhanbad districts and Katri Nala further east. From the southern side Garga Nala near the western boundary of the district and Gobai or Gowai Nala meeting Damodar east of Bhojudhi are its tributaries of some significance.

The Barakar river is the most important tributary of the Damodar and their confluence marks the eastern border of the district. Originating from the northern flanks of the Chotanagpur hills in Hazaribagh district, this river has a general southeasterly course within Dhanbad district until it abruptly veers to south beyond the Durgapur hills. In general, the drainage pattern within the district can be described as "dendritic".

## 2.20.2 Climate

One experiences in the Dhanbad district, a dry and hot summer and a dry and cold winter with an intermediate monsoon period from the middle of June to the end of September. The summer is extremely hot, whereas the winter from November to February is very pleasant with temperature varying 8˚C to 34˚C. After February, the climate becomes warmer till the rains break in the middle of June. The temperature during these four months from March to June usually varies from 13˚C to 45.5˚C. During the remaining months, July to October, which include the rainy season, temperature usually ranges from 15˚C to 36˚C. Average rainfall of the area is 1310.6 mm, most of which is precipitated during the monsoon months. The rainfall around Parashnath hills is reported to be more than the average.

## 2.20.3 Geology

The oldest geological formations in the district are a group of crystalline metamorphites of Archaean (Dharwar) age which form the basement. Over these rocks were deposited in slowly sinking faulted troughs (basins), the Lower Gondwana group of sedimentary strata including the coal-bearing beds. Superficial deposits of alluvial sands of rivers and streams and residual soils from the weathering of bed rocks, are recent formation formed during the Quaternary period. The soils of the district are mostly of the residual type. High temperature and fairly copious rainfall have led to the formation of lateritic type of soil from rocks of Archaean metamorphic complex exposed in greater part of the district as also from the Lower Gondwana sandstones in the west-central and east-central parts.

## 2.20.4 Potential of Ground Water

Weathered residuum and the immediately following fractured zones in the consolidated and semi-consolidated rocks forms the potential aquifers where groundwater occurs under water table condition. Saturated thickness of this phreatic aquifer is in the range of 0.8-10 m with an average of 3.0 m in February-March. Aquifers are found to be thicker in the schistose and sedimentary rock covered areas. Depth to water levels vary from 1.5-11.5 m bgl in pre-monsoon time, the deeper water levels being found in the northern and southern parts of the district in blocks adjacent to Barakar and Damodar rivers. Groundwater flow in the phreatic aquifer is towards the big rivers and from the northwest to the southeast conforming with the general slope of the country. Groundwater also occurs under confined to semi-confined state in deeper fractures in the depth range 15-91 m below ground level.

# 2.20.5 Population

As per 2001 census, the population of Dhanbad metropolitan city is 10,64,357. According to 2001 census, the literacy rate in the city was 64.94% and the participation of the male was found to be 61.3% and that of the females was 38.7%. The city has a sex ratio of 834 females for every 1000 males.

# 2.20.6 Water Supply

The main source of water supply in Dhanbad city is Damodar river and Topchachi lake. The water demand of the city is estimated to be 30 MLD. To fulfil this demand, about 3 MGD is supplied from Topchachi lake and 21 MGD is being supplied from Damodar Headwork at Jamadobha. Rest of the demand is being fulfilled by municipal corporation though hand pumps (about 6000), open dug wells (about 200) and HYDT (high yield drilled tubewells) about 15 nos.

# 2.20.7 Waste Water Generation

The treatment of water is carried out by MADA (Mineral Area Development Authority). There are two filtration plants one at Jamadobha and other at Topchachi with design capacity of 9 MGD and 3 MGD respectively. Total solid waste generation of the city is about 50 trips/day. Treatment of the waste is being done by low land filling using Vermi Composit method. The landfill site is located in Matkuria.

# 2.20.8 Status of Industries

Dhanbad is a well developed town because of mining activity in the area. The economy of Dhanbad is mainly dependent upon coal and coal based industries.Tata Steel has set up mines in the area. Coal washing and coke making are the main coal related industry in the city. Other major companies having a presence in the mining activities of this city are : IISCO (Indian Iron And Steel Company), BCCL (Bharat Coking Coal Ltd). BCCL a subsidiary of the CCL (Coal India Ltd) is the largest operator of steel mines in this area and has mostly open cast mines, whereas Tata Steel has mostly underground mines. The total number of small scale industries registered is about 300, out of which 150 are coal based and 150 of other types. There are four industrial areas located in the city. The details of industries existing in these industrial areas are as under :

| S. No. | Industrial Estate/Area | Type of industries |
|---|---|---|
| 1. | Govindpur | Coal based industries hard coke and soft coke, Refractories |
| 2. | Mirsa | Coal based industries hard coke and soft coke, Refractories |
| 3. | Baliyapur | Coal based industries hard coke and soft coke, Refractories |
| 4. | Baghmara | Coal based industries hard coke and soft coke, Refractories |

## 2.20.9 Petroleum Storage

There are four petroleum storages existing in Dhanbad city, each of Hindustan Petroleum Corporation Ltd. (HPCL), Indian Oil Corporation Ltd. (IOCL), Bharat Petroleum Corporation Ltd. (BPCL) and Indo Burma Petroleum Co. Ltd. (IBP) exists in Purana Bazar. The total number of petrol pump of different agencies in the metropolitan city is 11. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 5 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 2 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 1 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 3 |
| | Total | 11 |

## 2.21 JAMSHEDPUR

The metropolitan city Jamsehdpur is an industrial city located in district Singhbhum of the state of Jharkand, founded by the late Jamshedji Nusserwanji Tata as Sakchi. In 1919 Lord Chelmsford named it Jamshedpur, in honour of its founder. It is bounded by 22°48′ N latitude and 86°11′ E longitude. Jamshedpur is home to the first private Iron and Steel company of India, Tata Steel, and is commonly called "Tata" as a result of the company's significant presence. Jamshedpur is also called the Steel City. It is one of the greenest cities of India. The city recently won international acclaim when it was selected for the 2004 Global Compact City award from the UN in India, a true testimony indeed to its robust infrastructure, cosmopolitan outlook and strong industry. As per census, 2001, the population of Jamshedpur metropolitan city is 11,01,804. It is 28$^{th}$ largest town in India (population wise), and the second in the state of Jharkhand.

## 2.21.1 Physiography and Drainage

The metropolitan city Jamshedpur is one of part of Kandra-Jamshedpur-Ghatsila-Chakulia-Baharagora plain of Singhbhum district and has an average elevation of 135 m. But this plain is only deceptive because it actually consists of undulating grounds and is underlain by hard rocks at a very shallow depth. The slope in the area is generally towards east and southeast. It is located in the East Singhbhum district of Jharkhand state on the Chota Nagpur plateau and is surrounded by the beautiful Dalma Hills and bordered by the rivers Subarnrekha and Kharkhai in the north and west respectively. Singhbhum district is mostly covered by crystalline and metamorphic rocks, which on weathering give rise to red soils. The colour of the soil is due to a wide diffusion of its iron content, rather than a high proportion of it. The soils range from gravelly and light coloured varieties of the uplands to the fertile, deepdark varieties of the plains and valleys. The soils are generally poor in nitrogen, phosphorous and humus. Some patches are comparatively rich in potash, iron, lime and magnesia. Red soils derived from laterites are of a different nature. Low level lateritic soils are composed of dark, heavy loams and clays. The soil is red, brown or dark in colour. The high level lateritic soil is barren for agricultural purposes. However all lateritic soils are very poor in lime and magnesia with deficiency in nitrogen.

## 2.21.2 Climate

The area experiences a humid climate, which is explained due to inland position and presence of hills. The day temperature is quite high in summer, generally around 43˚C occasionally reaching upto 48˚C. The monsoon starts from the second half of June and continues to September-October. During the onset, monsoon is generally accompanied by violent storms from northwest. The rains in monsoon times are, however, heavy with much lowering of temperature. The annual rainfall in Singhbhum district is recorded as 1434 mm. The winter, which starts after cessation of the monsoon, is really the most enjoying season of the area. Mean temperature in winter is recorded as 11˚C. Winter continues to the end of February.

## 2.21.3 Geology

The geology of the area is very interesting, inasmuch as diverse rock types are developed with a none-too-simple structure of Dunn. The areas surrounding Jamshedpur are rich in minerals, including iron ore, coal, manganese and lime. The rocks in the area depict a geoanticline, followed by Dalma syncline in the north. However, the most important structural feature in the area is occurrence of the Singhbhum shear zone, which runs for more than 200 km in a NW-SE arcuate fashion from beyond Goilkera in west to Baharagora in southeast, separating the less metamorphosed rocks to the south of it from the more metamorphosed zones in the north.

## 2.21.4 Potential of Ground Water

The area is essentially underlain by hard and consolidated rock and only about 10% of the total area of the district shows the development of semi-consolidated rocks of Kolhan series and the Tertiary grits with gravels and unconsolidated alluvium, mainly along the lower reaches of Subarnrekha river etc. Semi-consolidated laterites are developed on Tertiary grits and gravels, as well as on other rocks at places. In the area, the rocks have weathering zones upto a maximum of about 20 m in topographical lows. Ground water is being withdrawn traditionally through the ages by dug wells in the weathered zones. The configuration of water table in the area follows closely topographical features, but it is a subdued repilica of topography. The depth of water table will therefore be more in upland areas than in topographic lows. It generally varies from about 1.5-16.0 m below ground level.

## 2.21.5 Population

As per 2001 census, the population of metropolitan city Jamshedpur is 11,01,804. According to 2001 census, the literacy rate in the city was 72.45% and the participation of the male was found to be 57.05% and that of the females was 42.95%. The city has a sex ratio of 753 females for every 1000 males.

## 2.21.6 Water Supply

Facilities in the metropolitan city Jamshedpur are maintained by Jamshedpur Utilities and Services Company Limited (JUSCO), a 100% owned subsidiary of Tata Steel.

The water demand of the metropolitan city Jamshedpur is met by Jugsalai, Mango and Jamshedpur municipalities. A supply of 2.8 MGD by Jugsalai and 3.0 MGD by Mango is being met. About 140 handpumps and 7 tubewells in Jugsalai, 550 handpumps and 5 tubewells in Mango and 500 handpumps and 15 bore wells in Jamshedpur are fulfilling the demand of water in city.

### 2.21.7 Waste Water Generation

Presently, there is no waste water treatment plant existing in the metropolitan city of Jamshedpur. As it is the one of developing city, the government of Jharkhand is planning to build waste water treatment plant in near future.

### 2.21.8 Status of Industries

Metropolitan city Jamshedpur is a modern, industrial city. The main industries include iron and steel, truck manufacturing, tinplate production, cement and other small and medium scale industries. The largest factory is that of Tata Steel (the erstwhile TISCO), and it is situated almost at the center of the city. The other major factory in the city is Tata Motors (formerly TELCO), which manufactures heavy vehicles & construction/earth moving equipment, Tata Tinplate (the erstwhile Tinplate Co. of India Ltd.) manufactures tinplate. Most of the Small Medium Enterprises (SMEs) are located just outside Jamshedpur, in the Adityapur Industrial Estate. Adityapur Industrial Area is the principal industrial area. About 652 industries are functioning in this area. The type of industries includes light engineering, mineral based, plastic and rubber, chemicals, food and beverage, pharmaceutical, electrical, sponge foam, LPG bottling plant etc.

### 2.21.9 Petroleum Storage

There are petroleum storage depots of Bharat Petroleum Corporation Ltd., Hindustan Petroleum Corporation Ltd., Indian Oil Corporation Ltd. at Burma Mines, Kali Mati road in the metropolitan city of Jamshedpur. The total number of petrol pump of different agencies in the metropolitan city is 54. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 10 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 16 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 14 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 14 |
| | Total | 54 |

## 2.22 KOLKATA

Kolkata (formerly Calcutta) is the capital of the state of West Bengal. A vibrant city with a distinct socio-political culture, Kolkata is noted for its revolutionary history, ranging from the Indian struggle for independence to the leftist and trade union movements. It is bounded by 22°33′ N latitude and 88°20′ E longitude. It is located in eastern India on the east bank of the River Hooghly. Kolkata city, under the jurisdiction of the Kolkata Municipal Corporation (KMC), has an area of 185 km². The Kolkata urban agglomeration, however, has continuously expanded and as of 2006, the urban agglomeration (Kolkata Metropolitan Area) is spread over 1750 km². The Kolkata Municipal Corporation (KMC), (formerly the Calcutta Municipal Corporation), established in 1876, is responsible for the civic maintenance and infrastructure of Kolkata. The city is divided into 141 administrative wards that are grouped into 15 boroughs. As per census, 2001, the population of Kolkata metropolitan city is 1,32,16,546. It is 2$^{nd}$ largest town in India (population wise), and the first in the state of West Bengal.

## 2.22.1 Physiography and Drainage

Kolkata is located in eastern India at in the Ganges Delta at an elevation ranging between 1.5 to 9 m. It is spread linearly along the banks of the River Hooghly in a north-south direction, which takes off from the main Ganga Channel at the head of the delta near Farakka as Bhagirathi which further down stream assumes the name Hooghly in the tidal stretch. Much of the city was originally a vast wetland, reclaimed over the decades to accommodate the city's burgeoning population. The Sundarbans National Park separates the city from the Bay of Bengal, which is located about 154 km to the south. According to the Bureau of Indian Standards, the town falls under seismic zone-III, in a scale of I to V (in order of increasing proneness to earthquakes) while the wind and cyclone zoning is "very high damage risk", according to UNDP report.

Several low lying depressions in the form of marshes, shallow lakes or Jhils around the area and most of these represent river scars of the past drainage channels of Bhagirathi. The master slope is towards south as indicated both by the course of the Hooghly and other major channels.

## 2.22.2 Climate

Metropolitan city Kolkata has a tropical climate and shows distinct climatological features throughout the year. The annual mean temperature is 26.8˚C; monthly mean temperatures range from 19˚C to 30˚C. Summers are hot and humid and maximum temperatures often exceed 40˚C during May and June. Winter tends to last for only about two and a half months, with seasonal lows dipping to the 12˚C – 14˚C between December and January. The highest recorded temperature is 43˚C and the lowest is 5˚C. Often during early summer, dusty squalls followed by spells of thunderstorm and heavy rains lash the city, bringing relief from the humid heat. The southeast monsoon rains lash the city between June and September and supplies the city with most of its annual rainfall of 1,582 mm. The highest rainfall occurs during the monsoon in August.

## 2.22.3 Geology

The Kolkata metropolitan area is located on the lower deltaic plain of the composite Ganga – Bhagirathi delta and is covered by the sediments deposited by the river system flowing through the area during Quaternary era. The sub surface geology of the area is completely obscured by a blanket of Recent sediments. Quaternary sediments consisting of clay, silt, various grades of sand and gravel underlie the city. These sediments are sandwiched between two clay beds, the lower one at depths between 250 and 650 m and the upper one ranging between 10 and 40 m in thickness.

## 2.22.4 Potential of Ground Water

Kolkata metropolitan area is underlain by Quaternary sediment consisting of a sequence of alternations of clay, silty clay, sand and sand mixed with occasional gravel. Clay horizon ranging generally in thickness from 30-50 m occurs at the top of the sedimentary sequence. The clay is underlain by coarse clastics consisting of sands of fine, medium and coarse texture which are occasionally mixed with gravel. These coarse clastics form the aquifers.

The sediments exhibit typical deltaic deposition showing facies variation at a few places with transition from aquiclude to aquitard. Sand and pebble form the aquifer materials although clay lenses often occur within the sand beds and individual sand beds often tend to thicker and thin out depending upon sedimentary facies variation. The principal productive aquifer generally occurs within the depth span of 60-180 m. A minor aquifer zone consisting of fine to medium sand, has also been found to exist within the depth span of 20-40 m.

Ground water occurs both under unconfined and confined conditions. Ground water in the shallow zone occurs under unconfined conditions. In Ballyganj, Dhakuria and Kasba area, shallow aquifer occurs within 12 m below ground level as thin lenses and ground water occurs here under unconfined condition. In the western part of the metropolitan area - Garden Reach-Barisha sector, aquifers occur down to 130 m are brackish and those below 160 m, are fresh water bearing, whereas in the north-east sector – Barisha towards Kalighat, the brackish – fresh water profile reverses with a thick fresh water aquifer overlying the brackish water aquifers. This aquifer extends eastwards to Jadavapur – Kasba area. In Santoshpur area, brackish water aquifers occur from top to a depth of 300 m below ground level. In Fort William – Ballyganj – Beliaghata sector, fresh water bearing aquifer occurs down to the depth of 20 m and is underlain by brackish water aquifer. In Dumdum area, fresh water aquifer exists from 12 m to drilled depth of 200 m below ground level. In western part of Dumdum i.e. in Kashipur area, brackish water aquifer occurs from top to drilled depth of 200 m below ground level. Another fresh water aquifer (sand gravel) of 60-100 m thickness occurs below a thick clay – slit horizon in Kalighat – Garia area.

## 2.22.5 Population

As per 2001 census, the population of metropolitan city Kolkata is 1,32,16,546. According to 2001 census, the literacy rate in the city was 75.74% and the participation of the male was found to be 56.17% and that of the females was 43.83%. The city has a sex ratio of 780 females for every 1000 males.

## 2.22.5 Water Supply

With the expansion of the urban complexes, industrial development and rise in population growth, the total demand for water has increased many fold. The KMC supplies potable water to the city, sourced from the River Hooghly. The water is purified and treated at Palta water pumping station located in North 24 Parganas. The water supply from surface water sources is inadequate. The water demand of the metropolitan city Kolkata is estimated to be 326 MGD and about 65% of the demand is being met by the municipal corporation. The total ground water intake is 25 MGD. There are 325 borewells working in the city.

## 2.22.6 Waste Water Generation

There is approximately 1.1 MLD waste water generation in the metropolitan city. Three waste water treatment plants are treating waste water of the city of the capacity of 220 MGD, 5 MGD and 8 MGD. The municipal solid waste generated is about 2800 metric tonnes per day. The disposal site for dumping solid waste is located at Dhapa to the east of the town. Almost all of Kolkata's daily refuse of 2500 tonnes is transported to the dumping grounds in Dhapa. Agriculture on this dumping ground is encouraged for natural recycling of garbage and sewer water. Parts of the city still lack sewage facilities leading to unsanitary methods of waste disposal.

## 2.22.7 Status of Industries

Kolkata is home to many industrial units operated by large Indian corporations with products ranging from electronics to jute. Some notable companies headquartered in Kolkata include ITC Limited, Bata India, Birla Corporation, Coal India Limited, Damodar Valley Corporation. The principal industrial areas within Kolkata Urban areas are Bahela Industrial Estate, Durgapur, Howrah and Tartala. The details of industries existing in these industrial areas are as under:

| S. No. | Industrial Estate/Area | Type of industries |
|---|---|---|
| 1. | Bahela Industrial Estate | Chemical, Pharmaceutical, Jute |
| 2. | Tartala | Confectionery, LPG, Carbide factory |
| 3. | Salt Lake | TV, Air conditioners, I T industries |

## 2.22.8 Petroleum storage

There are petroleum storage depot at Budge – Budge and Mouni Gram. The total number of petrol pump of different agencies in the metropolitan city is 51. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 11 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 17 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 15 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 8 |
| | Total | 51 |

## 2.23 AMRITSAR

The metropolitan city Amritsar is located in the northwest part of India in the State of Punjab. It is bounded by 31°38′ N latitude and 74°52′ E longitude. Amritsar municipal limit cover an area of about 50 km$^2$. The metropolitan city has highest seat of Sikhs "The Harimandir sahib" populalry known as Golden Temple and is the spiritual and cultural centre of the Sikhs Religion. The city is dominated by the history of the Sikhs and many of their sacred shrines are found in and around the city. The city has central old city called walled city. The metropolitan city is the administrative centre for the Amritsar district. Metropolitan city Amritsar developed from a small village pool to a business centre.

However, it did not become the industrial centre of Punjab due to its proximity to the volatile Indo-Pak border. The metropolitan city is progressing very fast as more and more new shopping malls, hotels and multiplexes are coming up. The municipal area is further divided into five administrative blocks. As per census, 2001, the population of Amritsar metropolitan city is 10,11,327. It is 33rd largest town in India (population wise), and the second in the state of Punjab.

## 2.23.1 Physiography and Drainage

The area forms a part of the almost flat and level alluvial plains. The elevation of alluvial plains ranges from 175 m in SW to 245 m in NE and general slope of the area is towards south-west. The right bank of Beas and Satluj rivers form upland areas and are locally called 'dhaia'. The difference of ground elevation and river bed is about 8-12 m. The perennial Ravi, Beas and Satluj rivers which form the northern and southern boundary of the district form the main drainage system. The area is also drained by Patti, Kasur and Sakki nalas. The Upper Bari Doab canal along with its various tributaries also traverses the area.

## 2.23.2 Climate

The climate of the area is tropical type with three well defined seasons – the winter season begins towards the beginning of December and extends to the middle of March. The weather is usually cold and night temperature often falls to 1˚C. The summer season extends from the end of March to the end of June. During these months the maximum temperature is usually between 36˚C to 43˚C. The principal precipitation occurs during south-west monsoon period i.e. from July through September. The normal annual rainfall of the area is recorded to be 700 mm.

## 2.23.3 Geology

The area is underlained by the thick sequence of the alluvial deposits of quaternary age which are a part of Indus basin. Maximum depth drilled in the alluvium is 500 m but nowhere the bed rock was encountered. The alluvium consists of alternative beds of sand, silt and clay and is usually overlain by a very thin layer of loam. Concretions of impure calcium carbonate called 'Kankar' are distributed in all horizons. Lateral farcies changes are common feature in the area. The entire alluvial thicknesses down to the depth of installation of wells seem to behave as a single aquifer complete in the area. However, it is possible to differentiate different active sedimentation cycles, each separated by clayey sediments. Within each sedimentary cycle, there are layers of sands and clays, which are local in nature.

## 2.23.4 Potential of Ground Water

In the north-eastern part of the area, thickness of the permeable granular zones varies from 22 to 95 m. Within the granular zones, thin speaks of clays also occur. The thickness of clay beds varies from 3 to 14 m. This clay beds are persistent in nature except around Amritsar and Jandiala where these pinch out at the shorter distances. The thickness of the water table aquifer varies from 20 to 40 m and it extends maximum upto 50 m depth below ground level. The permeable granular material mainly consists of fine to medium sand. In the south-western part of the area, there are 6 to 8 permeable granular zones separated by clay beds. The thickness of these ranges between 15 to 85 m and aquifers are composed of fine to medium sand. The beds are laterally and vertically extensive in nature. The thickness of these clay beds varied from 10 to 45 m. In the extreme south-western part, the thickness of the bed is maximum. The clay bed contains some kankar well. The water table aquifer extends upto 10 to 30 m below ground level. The cumulative thickness of sand is more in the north-easten part as compared to south-western of the area.

Deeper water levels are mostly confined to areas adjoining the Beas and Satluj rivers. The area is about 2 to 3 km wide and extends from village Varaich on the north-east of Mehdipur village in the extreme south-west of the district. In this strip of land, the depth to the water is in generally more than 6 m below land surface except in the flood plain of the rivers where it is as shallow as 1 m below ground level. Within Amritsar city, the depth to water varies from 6 to 8 m below ground level but in the area around the city, it ranges between 3 to 4 m. This is due to heavy pumpage of water supply tube wells in the city.

## 2.23.5 Population

As per 2001 census, the population of metropolitan city Amritsar is 10, 11,327. According to 2001 census, the literacy rate in the city was 69.83% and the participation of the male was found to be 55.45% and that of the females was 44.55%. The city has a sex ratio of 803 females for every 1000 males.

## 2.23.6 Water Supply

In Amritsar city, the drinking water is being served to the public from ground water sources. The citizens of Amritsar are receiving drinking water at rate of 220 MLD of good quality from ground sources (256 LPCD). Water is being drawn by digging wells and is pumped to the distribution network. There are 29 OHSR in the city. There are 190 power bore, 70 hand bore, and 12 water tanker in city for the supply of water.

## 2.23.7 Waste Water Generation

The generated solid waste of the city is being collected by the Amritsar Municipal Corporation and is being disposed off at Chhiata, Fatehpur and Mall Mandi. The landfill site of the city is situated on the Chabal road.

## 2.23.8 Status of Industries

The industrial areas/estate in Amritsar Urban areas include Batala Road, Vishnu Nagar, Sultan Vint Road, Focal Point, Tarantaran Road, Mazitha Road, Verka Bye Pass, Putlighar, Islamabad, Lohri Gate Parthawa. The main industries existing in these areas are related to food, textile, readymade garments and tailoring, leather goods, wood based, paper, dying & chemical, detergent, medicine, machine, agriculture, electrical goods and appliances, surgical items, auto and cycle parts, floor mills, cold storages etc. The total number of small scale industries functioning is approximately 8000.

## 2.23.9 Petroleum Storage

The total number of petrol pump of different agencies in the metropolitan city of Amritsar is 190. The distribution of petrol pumps is given below:

| S.No. | Name of the Agency | No. of Petrol Pump |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 65 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 28 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 75 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 22 |
| | Total | 190 |

## 2.24 KANPUR

The metropolitan city Kanpur is the largest industrial centre of Uttar Pradesh State. It is bounded by 26°28′ N latitude and 80°21′ E longitude. Kanpur is situated in the middle of the Ganga Valley, on the western bank of the river Ganga. Kanpur has its older closely built core about a kilometre away from the river Ganga. Between this core and the Ganga river lies the industrial zone on the west and the administrative zone on the east. Kanpur municipal limit cover an area of about 278 $km^2$. The city has considerably grown up in recent times and developed in all field of activities. Science and technology accelerated the pace of industrial development which in turn, gave rise to increase in population. The municipal area is further divided into six administrative zones. As per census, 2001, the population of Kanpur metropolitan city is 26,90,486. It is $10^{th}$ largest town in India (population wise), and the first in the state of Uttar Pradesh.

## 2.24.1 Physiography and Drainage

Kanpur metropolis forms a part of Ganga sub-basin in the central Indo-Gangetic plain. It exhibits more or less a flat topography with the master slope from north-west to south-east. The average elevation of the land surface is 125 m above mean sea level. The area is drained by the river Ganga and its tributary Pandu. The low land or Younger Alluvial plain has been identified as flat to gently sloping and slightly undulating terrain of large areal extent, formed by river deposition, and is limited along river Ganga with the breadth not exceeding 5 km. The sediments comprise of Recent unconsolidated alluvial material of varying lithology. The fluvial land-forms such as palaeochannel, meander scar and oxbow lakes are common features. Further west of Younger Alluvial plain is the area of stable upland which has been produced by extensive deposition of older alluvium comprising of coarse to fine sand, silt and clay. The patches of salt encrustations have been reported in the area around Panki and Chakeri.

## 2.24.2 Climate

The area experiences sub-tropical climate with average normal annual rainfall as 833.5 mm which is mostly received through the south-west monsoon. The mean maximum monthly temperatures 41.7˚C has been recorded during May and minimum 22.8˚C in January.

### 2.24.3 Geology

Geologically, the area is underlain by Indo-Gangetic alluvium of quaternary age formed by fluvial processes comprising of clay, silts, sands of various texture and kankar in varying proportion. The granetic bedrock sloping towards north by 1° to 2° is encountered at 502 m (Panki) below ground level.

### 2.24.4 Potential of Ground Water

There is disposition of different aquifers, presumably because of transgression and regression phases of the rivers. The first sandy layer which is usually being tapped by private hand pumps occurs at 12-15 m below ground levels whereas the second and third tables are encountered at 28 to 33 m and beyond 50 m. Groundwater in these aquifer zones occurs under unconfined and semi-confined conditions. The depth of water table ranges from 2.4 to 10.88 m. Water table fluctuation varies from 0.99 to 1.69 m. Deposits of sand are the main source of groundwater, occurring in unconfined to semi-confined conditions.

### 2.24.5 Population

As per 2001 census, the population of metropolitan city Kanpur is 26,90,486. According to 2001 census, the literacy rate in the city was 72.85% and the participation of the male was found to be 54.29% and that of the females was 45.71%. The city has a sex ratio of 868 females for every 1000 males.

### 2.24.6 Water Supply

Rapid urbanization and industrialization have increased in demand of water for domestic as well as industrial requirements. The main source of water supply for the Kanpur Municipal Corporation Area is river Ganga, Lower Ganga Canal and 130 handpumps operated by Kanpur Jal Sansthan, Kanpur. About 80% of municipal corporation area is fed by water supply. Presently, water demand of the metropolitan city is 435 MLD and 375 MLD is being supplied to the city after purification. Out of this supply, 200 MLD is being met with river Ganga through Bhaironghat Pumping Station, 40 MLD through Lower Ganga Canal, 10 MLD through Gujaini Water Works and rest 125 MLD through underground sources. There are 26 zonal pumping stations and 22 overhead tanks existing in the city.

### 2.24.7 Waste Water Generation

The main causes of pollution of ground water in Kanpur are indiscriminate dumping of municipal and industrial solid waste, age-old leaking sewerage system, improper operation of treatment plant and disposal of partially treated waste water though unlined channel. Water is being purified by using well known techniques e.g. coagulation and filtratrion. There are 16 slowsand and 10 constant rate rapidgravity filters. Under World Bank Project, a declining rate filtration plant of capacity 200 MLD is constructed which comprises of 20 rapid gravity filters.

The sewerage system of the city is more than 100 years old. There is a network of about 100 km long main trunk sewer lines and about 857 km long branch sewer lines in the city. Thirteen sewerage pumping stations are operated by Kanpur Jal Sansthan in the city. There are sewage treatment plants of capacity 5 MLD and 36 MLD at Jajmau. The total solid waste generation of the city is estimated to be 1100-1200 MT/day, out of which about 900-1000 Mt/day is being disposed off. The landfill site of the city is situated in the village Bingava on the Hamirpur road.

### 2.24.8 Status of Industries

The principal industrial areas within Kanpur Urban areas are Jajmau, Pokharpur, Fazalganj, Panki and Rooma. The total number of small scale industries registered is 12000. The details of industries existing in these industrial areas are as under:

| **S. No.** | Industrial Estate/Area | **Type of industries** |
|---|---|---|
| 1. | Jajmau industrial area | Tanneries |
| 2. | Pokharpur area | Dal mills |
| 3. | Fazalganj factory area | Engineering goods, cold storages, chemical based |
| 4. | Government industrial estate, Kalpi road | Miscellaneous, mechanical, biscuits, confectioneries, cold storages, food, chemical |
| 5. | Cooperative industrial estate, Dadanagar | Miscellaneous, mechanical, biscuits, confectioneries, cold storages, food, chemical |
| 6. | Panki industrial area, Phase I-V | Miscellaneous, mechanical, chemical |
| 7. | Uptron estate, Panki | Electronics, engineering goods |
| 8. | Rooma industrial area, Jajmau, Fatehpur | Housery items, textiles |

### 2.24.9 Petroleum storage

There is only one petroleum storage of Indian Oil Corporation Ltd. (IOCL) existing in Kanpur city at Panki. The total number of petrol pump of different agencies in the metropolitan city is 88. The distribution of petrol pumps is given below:

| **S.No.** | **Name of the Agency** | **No. of Petrol Pump** |
|---|---|---|
| 1. | Bharat Petroleum Corporation Ltd. (BPCL) | 27 |
| 2. | Hindustan Petroleum Corporation Ltd. (HPCL) | 23 |
| 3. | Indian Oil Corporation Ltd. (IOCL) | 25 |
| 4. | Indo Burma Petroleum Co. Ltd. (IBP) | 13 |
| | Total | 88 |

## 2.25 Allahabad

There is an increase in the spurt of industries which in turn also increase the environmental pollution due to emissions and waste generated from these industries. The industrial pollution due to its nature has potential to cause irreversible reactions in the environment and hence, is posing a major threat to sustainable development. As the carrying capacity of the environment is limited and some ecosystems are more susceptible to adverse environmental impacts than others, the unplanned and haphazard location of industries might substantially increase the risk to the environment. The ground water study is essential for assessing the ground water quality. The observational data can be profitably utilized for taking up studies regarding behaviour of ground water table and the pattern of ground water table variations over a number of years, its relation to rainfall and irrigation and latest conditions regarding water table in the State. These studies are of vital importance from the point of view of development of water-logging. Vast area of state of Uttar Pradesh is already water-logged, and any addition to such area is not in the interest of the state. It, therefore, becomes imperative to have a careful watch over the behaviour of ground water table since rise of ground water can be permitted only to a certain extent. The study of behaviour of water table can prove of immense importance in enabling us to act judiciously.

Ground water pollution is an impairment of water quality by chemicals, heat or bacteria to a degree that does not necessarily create an actual public health hazard, but does adversely affect such waters for domestic farming, municipal or industrial use. The pollution can originate point or distributed sources within the recharge area of an aquifer. The rise of ground water pollution is highest in urban areas where large volumes of wastes are concentrated into relatively small areas. The risk is further increased if they are located on areas of permeable surface deposits. Further, the intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and already have resulted in many incidents of ground water contamination. The ground water moves very slowly, sometimes many years may lapse after the start of pollution affected water shows up in a well. Similarly, many years may be required to rehabilitate contaminated aquifers after the sources of pollution have been eliminated. Sometimes this delay may force abandonment of wells and may require costly development of alternate water supplies. Prevention of contamination thus is the best way for protecting ground water quality. Slow movement of ground water is favourable, as radioactive substances, bacteria and viruses may decompose or die, with the passage of time. In such cases, long underground detention times may result in essential removal of the undesired substances. Degradation of ground water quality can take place over large areas from plane or diffused sources like deep percolation from intensively farmed fields or it can be caused by point sources such as septic tanks, garbage disposal sites and oil spills or other accidental entry of pollutants into the underground environment. A third possibility is contamination by line source of poor quality water like seepage from polluted streams.

Ground water is an important component of the water system for domestic, industrial and agricultural purpose. It is commonly used source for drinking water for urban and rural sectors in India. Ground water is a renewable natural resource with a relatively short and shallow circulation with close dependence on precipitation and surface water. Ground water once was supposed to be the hygienic, secure and safe for human consumption. Ground water is now being gradually polluted by human being because of the intense industrial activities. The quality of ground water depends upon the characteristics and type of the sub surface soil and nature of recharge water. Water applied at the ground surface in the form of rainfall and irrigation has to pass through unsaturated zone before leaching the water table. Water in contact with sediment material may result in leaching out of more soluble species, precipitation of saturated species and the formation of colloidal oxides via chemical reactions. The quality of ground water varies from place to place and is primarily governed by the hydrological characteristics of the region.

Today the accelerated pace of development, rapid industrialization and population density have increased demand of water resources. Ground water, a gift of nature, is about 210 billion $m^3$ including recharge through infiltration, seepage and evaporation. Out of this nearly one third is extracted for irrigation, industrial and domestic use, while most of the water is regenerated into rivers.

Over 98% of the fresh water on the earth lies below its surface. The remaining 2% is what we see in lakes, rivers, streams and reservoirs. Of the fresh water below the surface, about 90% satisfies the description of ground water, that is, water which occurs in saturated materials below the water table. About 2% water occurs as soil moisture in the unsaturated zone above the water table and is essential for plant growth.

Ground water acts as a reservoir by virtue of large pore space in earth materials, as a conduit which can transport water over long distances and as a mechanical filter which improves water quality by removing suspended solids and bacterial contamination. It is the source of water for wells and springs, that is, the recommended source of rural domestic use. It is replenished by precipitation through rain, snow, sleet and hail. Ground water that can be used annually is about 416 Cu km. which would increase to 1108 Cu km. by 2025 A.D.

Today human activities are constantly adding industrial, domestic and agricultural wastes to ground water reservoirs at an alarming rate. Ground water contamination is generally irreversible i.e. once it is contaminated; it is difficult to restore the original water quality of the aquifer. Excessive mineralization of ground water degrades water quality producing an objectionable taste, odour and excessive hardness. Although the soil mantle through which water passes acts as an adsorbent retaining a large part of colloidal and soluble ions with its cation exchange capacity, but ground water is not completely free from the menace of chronic pollution.

It is always better to protect ground water first rather than relying on technology to clean up water from a contaminated source. Ice caps and glaciers account for 76.6% of fresh water source on earth, followed by ground water 22.7% and surface water, a mere 0.5%. Despite ground water being a major source of drinking water it is often disregarded because of a lack of knowledge about its behaviour. Ground water is a principal source of drinking water, particularly in rural areas and also for irrigation, but it has earlier been polluted or overused, making it impotable or resulting in its depletion. In terms of percentage, the pollution of ground water, is however, quite small. In cities and villages, pollution activities are high and these are affecting human health as well as the environment. Although only a small fraction of the total ground water resources are affected by human activities, but the proportion of local usable resources affected are much higher and becoming critical in some areas close to the major population centers. Developed countries like North America, Europe and Australia are now developing ground water protection policies which would hopefully lead to more sustainable development. The techniques are also available for cleaning up the polluted or contaminated ground water sources, but these are very expensive.

India has a good industrial infrastructure in core industries like metals, chemicals, fertilizers, drugs and petroleum, industries like plastics, pesticides, detergents, fuels, solvents, paints, dyes and food additives, which release effluents and emissions, polluting soil water-plant ecosystem. The disposal of solid and liquid wastes containing heavy metals like lead, nickel, chromium, molybdenum and mercury on land or water bodies, leads to heavy metal contamination of the soil-water-plant-animal ecosystems.

**Factors Affecting Ground Water Pollution:** The extent of ground water pollution depends on the following factors:

1. Rain Fall Pattern,
2. Depth of Water Table,
3. Distance from the Source of Contamination, and
4. Soil Properties such as Texture, Structure and Filtration Rate.

**Source of Contamination in Ground Water :** Underground sources of drinking water, especially in outskirts of larger cities and villages are highly polluted. Ground water is threatened with pollution from the following sources:

1. Domestic Wastes
2. Industrial Wastes
3. Agricultural Wastes
4. Run off from Urban Areas
5. Soluble Effluents

**1. Domestic Wastes:** Domestic wastes and methods of their disposal are of primary concern in urban areas. Prime factors responsible for deteriorating the water quality include pathogenic organisms, oxygen demand, nutrients and solids from domestic wastes. Solid wastes are the potential source of contamination as they are partly burned and partly incorporated into the soil and pose serious danger to the ground water.

**2. Industrial Wastes:** Most industries generally produce wastes containing toxic heavy metals along with hazardous organic and inorganic effluents. These chemicals contaminate the ground water and severely pollute it.

**3. Agricultural Wastes:** Fertilizers, pesticides, insecticides, herbicides, processing wastes and animal wastes etc. are constantly added to the water. Leachates from agricultural land containing nitrates, phosphates and potash, move downward with percolating water and join the aquifers below posing danger to the ground water.

Throwing rubbish and other unwanted things into the water are not only the cause of water pollution, but a harmless activity such as farming could lead to some thing as insidious as nitrate pollution. Rising nitrate levels have raised an alarm because of the possibility of adverse effect on humans and animals. Methaemoglobinaemia or blue baby disease, is caused by the reaction of nitrate with haemoglobin, the oxygen carrier in the blood, producing methaemoglobin, which strangles the oxygen carrying capacity of the tissue. Some claim that nitrate can wear down body’s immune system while its derivatives may be carcinogenic. Nitrate also causes eutrophication, although in India and other tropical regions, it is thought that phosphates are more to be blamed for this asphyxiation of water bodies.

**4. Run off from Urban Areas:** Effluents from urban areas contain large concentration of oils, grease, nutrients, heavy metals and detergents. The detergents being soluble can pass through the soil and pollute ground water. Raw sewage dumped in shallow soakpits and seepage from polluted lake, pond or stream also pollute water. Rainfall could pickup substantial contaminants from dust and air and join the aquifer below. The infiltration of liquids containing toxic pollutants may cause pollution in sandy soils and well waters.

Supply of potable water has been affecting the contamination of water resources in most of the developing countries. Rivers, lakes and ground water have been polluted by industrial effluents, pesticides and fertilizers from agricultural runoff and urban waste. Chronic water scarcity is common in areas where ground water has been overdrawn for irrigation, industrial use or to meet the requirements of urban population. Clearing of forests which increase surface runoff and reduce ground water have made the situation worse. Many countries are fast using up their ground water and moving from a situation of crises to disaster.

**5. Soluble Effluents:** Several soluble effluents pollute the ground water critically. The extent of pollution is more in sandy soils and humid regions having high water table conditions. Global withdrawals of water have grown by a factor of over 6 between 1900 and 1995 - more than double the rate of population growth. This is because of increasing water needs for agriculture, industrialization and greater human uses in urban cities. According to WHO, about 460 million people, more than 8 % of the world's population, live in countries that can be considered to be highly water stressed. About 25% of world's population lives in countries where the consumption of fresh water is so high that they are likely to move into situation of serious water stress.

Agriculture takes about 70% of the water withdrawals, often rising to 90% in dry tropics. Water withdrawals for irrigation has increased by more than 60%, which has coincided with the green revolution. High yielding crop varieties require a lot of water. Now water withdrawals are so high that water bodies such as rivers and lakes, have shrunk in size. A direct impact of this has been on the levels of ground water. Increasing use of ground water has pushed the water table lower. This can have serious effects on the flow of rivers, especially during dry periods, which is vital for the aquatic ecosystem. Along the coasts, increasing ground water withdrawals have led to the ingress of saline water into ground water. Other potential sources of ground water contamination are waste water treatment lagoons, mine spills, transport accidents, seepage pits, urban and rural garbages, earthen septic tanks, refuse dumps, barnyard manures, leaching and downward movement of pollutants.

**Harmful Effects of Ground Water Pollution :**

Ground water pollution causes high extent of damage to soil, plants and animals including man.

**Harmful Effects On Man :**

a) Polluted ground water is the major cause for the spread of epidemics and chronic diseases in man. It causes typhoid, jaundice, dysentery, diarrhoea, tuberculosis and hepatitis.
b) Water contaminated by fibres i.e. asbestos causes fatal diseases like asbestosis and lung cancer.
c) Ground water in excessive rainfall areas contain iron in toxic amounts as much as 20 mg/L. In deep tube wells, iron exists as ferrous ion which on taking out rapidly changes to light yellow orange colour due to oxidation and precipitation as ferric hydroxide.
d) The woollen industries contribute large amounts of toxic metals such as Hg, Ni, Cu, Cr, Fe, and cyanides to ground water causing skin and stomach diseases in man.

**Harmful Effects On Soil:**

a) The use of polluted ground water for irrigating agricultural fields severely damages crop and decreases grain production.

b) Polluted water acutely affects soil fertility by killing bacteria and soil microorganisms.
c) Contaminated ground water increases alkalinity in the soils.
d) Ground water pollution affects plant metabolism severely and disturbs the whole ecosystem.

**Table - 1.1** shows the occurrence of ground water pollution in India and the problematic pollutants in groundwater quality in major cities in UP.

**TABLE – 1.1**

**GROUND WATER POLLUTION IN INDIA**

| Pollutant | State | Place of occurrences |
|---|---|---|
| **Salinity (Inland)** | Maharashtra | Amravati, Akola |
| | Bihar | Begusarai |
| | Haryana | Karnal |
| | Rajasthan | Barmer, Jaisalmer, Bharatpur, Jaipur, Nagaur, Jalore & Sirohi |
| | **U.P.** | **Mathura** |
| Salinity (Coastal) | Andhra Pradesh | Vishakapatnam |
| | Orissa | Puri, Cuttak, Balasore |
| | West Bengal | Haldai & 24 Pargana |
| | Gujarat | Junagarh, Kachch, Varahi, Banskanta & Surat |
| **Fluoride** | Kerala | Palaghat Krishna, Ananipur, Nellor, Chittoor. |
| | Andhra Pradesh | Cuddapah, Guntur and Nalgonda |
| | Gujarat | Banskanta, Kachch & Amreli |
| | Haryana | Hissar, Kaithal & Gurgaon |
| | Orissa | Bolangir, Bijapur, Bhubaneshwar and Kalahandi |
| | Punjab | Amritsar, Bhatinda, Faridkot, Ludhiana & Sangrur |
| | Rajasthan | Nagaur, Pali, Sirohi, Ajmer & Bikaner |
| | Tamil Nadu | Chengalput, Madurai |
| | **U.P.** | **Unnao, Agra, Aligarh, Mathura, Ghaziabad, Meerut & Rai Baraili** |
| Sulphide | Orissa | Balasore, Cuttak & Puri |
| **Iron** | **U.P.** | **Mirjapur** |
| | Assam | Darrang, Jorhat, Kamrup |
| | Orissa | Bhubaneshwar |
| | Bihar | E. Champaran, Muzaffarpur, Gaya, Manger, Deoghar & Madubani |
| | Rajasthan | Bikaner, Alwar, Bharatpur |
| | Tripura | Dharmnagar, Kailasanar, Ambasa, Amarpur & Agartala |
| | West Bengal | Madnipur, Howrah, Hoogly and Bankura |
| **Manganese** | Orissa | Bhubaneshwar, Athgaon |
| | **U.P** | **Muradabad, Basti, Rampur & Unnao** |
| Arsenic | West Bengal | Malda, Murshidabad, Nadia, 24 Pargana |
| Nitrate | Bihar | Patna, East Champaran, Palamu, Gaya, Nalanda, Nawada and Banka |
| | Andhra Pradesh | Vishakapatnam, East Godvari, Krishna, Prakasam, Nellor, Chittoor, Anantpur, Cuddapah, Kurnool, Khamam and Nalgonda |
| | Delhi | Naraina, Shehadr (Blocks) |
| | Haryana | Ambala, Sonepat, Jind, Gurgaon, Faridabad & Hissar |
| | Himachal Pradesh | Kulu, Solan, Una |
| | Karnataka | Bidar, Gulbarge and Bijapur |
| | Madhya Pradesh | Sehore, Bhopal & (West & Central Part of state) |
| | Maharashtra | Jalna, Beed Nanded, Latur, Osmanabad, Solapur Satara, Sangli and Kolhapur |
| | Punjab | Patiala, Faridkot, Firozpur, Sangrur & Bhatinda |

| | | |
|---|---|---|
| | Rajasthan | Jaipur, Churu, Ganganagar, Bikaner, Jalore, Barmer, Bundi and Sawaimadhopur |
| | Tamil Nadu | Coimbatore, Penyar and Salem |
| | West Bengal | Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura and Purulia. |
| Chloride | Karnataka | Dharwad, Belgaum |
| | Madhya Pradesh | Bhind, Shagapur and Sehore |
| | Maharashtra | Solapur, Satara, Amravati, Akola & Buldana |
| | Rajasthan | Barmer, Jaisalmer, Jodhpur & Jalore |
| | West Bengal | Contai, Digha, Haldia |
| Zinc | Andhra Pradesh | Hyderabad, Osmania University campus |
| | Delhi | R.K. Puram |
| | Rajasthan | Udaipur |
| Chromium | Punjab | Ludhiana |

The available ground water resources of Uttar Pradesh are given in **Table - 1.2** below:

**TABLE - 1.2**

**GROUND WATER RESOURCES OF UTTAR PRADESH**

| S.N. | State | Total Reple-nishable Ground Water Resource (MCM/Yr) | Provision for Domestic Industrial and other uses (MCM/Yr) | Available Ground water for irrigation resource in net terms (MCM/Yr) | Net Draft (1993) (MCM/Yr) | Balance Ground water resources for future use (MCM/Yr) | Level of ground water develop-ment' (%) | Utilisable irrigation potential for land develop-ment (Mha) |
|---|---|---|---|---|---|---|---|---|
| 1 | Uttar Pradesh | 83820.85 | 12573.13 | 71247.72 | 26835.28 | 44412.44 | 37.66 | 16.79896 |
| Source: Ground Water Statistics 1996, Central Ground Water Board, MCM : Million Cubic Metres | | | | | | | | |

**OBJECTIVES OF STUDY:**

More than 90% of rural population uses ground water for domestic purpose. It is therefore extremely important to have detailed information and knowledge about the quality of ground water. Keeping this in view Central Pollution Control Board, New Delhi has assigned the project on "Assessment of Ground Water Quality of Metro City - Allahabad" to Pollution Control Research Institute (PCRI), BHEL, Haridwar with the following objectives:

**1. Assessment of Ground Water Quality during pre monsoon period located at**

INDUSTRIAL AREA, RESIDENTIAL AREA, SANITARY LANDFILL AREA, PETROL, DEPO/ADJOINING AREAS for ground water.

**2. Assessment of Ground Water Quality during post monsoon period located at**

INDUSTRIAL AREA, RESIDENTIAL AREA, SANITARY LANDFILL AREA, PETROL, DEPO/ADJOINING AREAS for ground water.

## 2.25.1 DESCRIPTION OF STUDY AREA

The district of Allahabad lies at tail end of Allahabad division to the south between latitude 24º 47’ and 25º 47’ N and longitude 81º 19’ and 82º 29’ E. On the North it is bounded by the districts of Pratapgarh and Jaunpur, the former being separated by the river Ganga for about one third of its boundary. On the East is the district of Varanasi and the district of Mirzapur on the Southeast. The southern boundary is formed by the State of Madhya Pradesh, and the district of Banda and Fatehpur bound it on the south-west and West. The length of the district from east to west is about 117 km and the breadth from north to south is about 101 km while the total area 7261 sq. kms. The district headquarters is located at Allahabad which is also known as Prayag, situated at the confluence of the great rivers the Ganga, the Yamuna and the mythical Saraswati.

Allahabad is one of the most important towns which are situated along the river Ganga. This great city is famous for the annual Magh Mela and for Maha Kumbh, which is held at every twelve years interval, the biggest Mela in the World **(Figure – 2.1)**.

The main town is bounded by river Ganga on Northern and Eastern sides, the river Yamuna and Doab plain forms its Southern and Western boundaries respectively. The Kanpur-Varanasi Road, in most of its length runs on the ridge line dividing the town in two parts. The area on the north of this road slopes towards Ganga whereas the area on the south side slopes towards river Yamuna.

The general information about Allahabad is as given below:

| S.N. | INFORMATION | DATA |
|---|---|---|
| 01. | Population | ~ 15 lacs as per 2001 Census |
| 02. | Area | 63.07 sq.kms |
| 03. | Altitude | 98 meters above sea level |
| 04. | Temperature Summer | 26.6 to 41.0 °C |
| 05. | Temperature Winter | 9.1 to 29.0 °C |
| 06. | Rainfall | 102.8 cms |
| 07. | Language | Hindi, Urdu & English |

Geographically the two important rivers namely Ganga and Yamuna divide Allahabad district into broad based vis-à-vis Trans-Ganga, Doab, Trans-Yamuna. The Trans Ganga region occupies the area North of Ganga river. The high bank of the Ganga is generally broken by ravines & drainage channels. The Doab region falls between the Ganga in the North and Yamuna in the South. Between the Ganga and its high ridge there is a strip of alluvial plain, at places very narrow but elsewhere widening out into broad stretch of sand and silt. Trans Yamuna region being the largest physiographic unit of the district and generally known as "Yamunapaar" lies to the south of the Yamuna.


**Figure – 2.1 Allahabad City**

The important characteristic feature is that the high banks of the Yamuna and the Ganga are highly dissected by numerous ravines which carry monsoon run off from the interior parts of the basin. Hillocks are significant in the area. Rocky out crops of various dimensions produce rugged topography. The highest altitude is 171.24 M above mean sea level while the lowest being 104.80 M above mean sea level.

Allahabad Jal Sansthan provides the existing water supply in the city. With the development of many new residential areas, the water demand has increased. The surface water supply is not adequate to meet this increased demand. The drinking water supply is drawn from surface and ground water. The source of surface water is river Yamuna. Deep tube wells, hand pumps and private bore wells are the main sources for extraction of ground water in the city to cater to the water demand of the population. The depth of ground water varies from 2 to 20 m in various parts of the city. Apart from municipal sources of water supply, a large number of consumers also have shallow hand pumps for augmenting their water requirements.

## 2.25.2 Physiography

The district is drained by river Ganga and its right bank tributary Yamuna and Tons broadly represents following geomorphic units:

1. Ganga Alluvial plain
2. Yamuna Alluvial plain
3. Vindhyan Plateau

No significant deposits are present over the cis Yamuna region. The important land forms observed in the alluvial plain area are the meanders, scrolls, pointbars, back swamps etc. In the Vindhyan plateau region the important land forms are mesa, butte and glacies. From ground water occurrence point of view and with reference to its yields prospects, the alluvial plain sediments are relatively the most potential ground water repositories which can sustain battery of tube wells to meet the demand of water of any degree.

Topographically Allahabad can be divided into three parts- the trans-Ganga tract or the Gangapar plain, the *doab* and the trans- Yamuna tract, These are formed by the two main rivers, the Ganga and the Yamuna. The trans Ganga part consists of the Soran, Phulpur and Handia tehsils. It is plain area but there are long belts of *Khadar* land. The high banks of the Ganga are covered with poor sandy soil. Belts of loam and *usar* lands also exist in this part. The doab tract comprises the Chail, Manjhanpur and Sirathu tehsils and lies between the Ganga on the north and the Yamuna on the south. It is rich and fertile. The land is plain and it consists of alluvial and light loam soils. In the south west the soil is dark and it resembles the mark of the adjoining parts of Madhya Pradesh. The trans Yamuna tract lies to the south of the Yamuna and comprises the Karchhana and Meja tehsils. It forms a part of Bundelkhand region. The ridge formed by the Ganga and the Yamuna which lies in the north of Karchhana is crowned with light sandy soil. The Kachhar land lies near the confluence of the Ganga and the Tons. The central parts of karchanna tehsil and some parts old meja tehsil consist of upland. The ranges of the vindhyan series of the Deccan plateau also lies in this tract. The Panna range lies for about 16 km. along the southern boundary of the district.

The area of forests is 20142 hectares which constitutes a small percentage of the total area of the district. Tehsils of Sirathu, Phulpur and Handia have no forest area in them. Dense forest areas exist in trans- Yamuna tracts. The common trees being dhak, kakor, aonla, jharberi, jamun, mahua, semal, khair, bahera and babul. The right bank of the Ganga has patches of babuls. These are also abound in tehsil Sirathu. In Meja tehsil alone haldu, ohhajan and teak are found. Mixed plantation of khair, babul, sheesham, neem and teak trees was also revised by forest department. Mango, mahua, guava, jamun and ber have been planted in grooves that gives a well wooded appearance.

## 2.25.3 Climate

Allahabad district is continental. The climate of Allahabad is tropical with moderate winter and severe extended summer. The nearest large body of water i.e. the Bay of Bengal is more than 700 kms eastward**.** Due to this, there is a large range of variation in temperatures of day and night. The Allahabad experiences both very dry hot summer and very cold winter every year. During winter the temperature ranges from 9.1ºC to 29ºC whereas in summer it ranges from 26.6ºC to 41.0ºC. Dust storms in summer and cold north winds in winter are common. The average normal maximum temperature has been observed as 47.8ºC during June and minimum 5ºC during January. The relative humidity of air varies from 20% in dry season to 84% during the rainy season. The highest relative humidity in the morning is 85% during August and the lowest being 30% in April. The evening relative humidity ranges between 15 % to 78 %. The district receives rainfall from south west monsoon from June to September. The average rainfall being 959.1 mm takes place normally in 53 days. The average normal rainfall of the city is varied from min 520.6 mm to the highest of 1276.5 mm. Total evaporation of Allahabad district is 1537.5 mm. The maximum is observed during May and June which are the peak summer months.

## 2.25.4 Hydrogeology

Ground water in the district occurs both in alluvium and the weathered and joined sandstones in areas which are underlain by the hard rocks. Two broad based hydrogeological units, namely, unconsolidated (Alluvium) and consolidated (hard rock) are the major components. The Alluvial formations occur in the Trans-Ganga and Doab region. Localised patches of Trans-Yamuna region are also covered by unconsolidated formations. Occurrence of consolidated formations is restricted primarily to Trans-Yamuna tract and this sizable area flanks the southern most segment of the district.

**1. ALLUVIUM AREA**

Ground water occurs within the primary porosity of alluvium sediments in the north, the aquifer materials are medium to coarse grained sands. The shallow aquifers occur under unconfined conditions. The records available from National Hydrograph stations indicate vide fluctuations in the depth of water table. It generally ranges between 2.0 M to 20 M below ground level. The significant variation in the depth of water table could be due to local geomorphic and other related factors. Field observations by government agencies indicates that by and large depth of water table is less than 15 M during premonsoon in the Trans-Ganga region whereas in Doab it stands in the depth range between 5 and 20 M. During post monsoon period, however depth to water table in the Trans-Ganga region ranges between 0.10 and 15.0 M bgl. The Doab region indicates the depth of water table ranging between 4.5 and 10.0 M bgl. The deeper depths to water table are observed normally all along the Ganga course. Depth to ground water level, as observed from tubewells constructed down to 255 Meters tapping deeper aquifers ranges between 6 and 20 Meters below ground water level.

The data recorded from National Hydrographs stations reveals that with respect to recharge condition mainly because of rainfall the water table has shown a tendency to rise to the tune of 2.5 M to 3.0 M. Due to the seasonal fluctuation the decline of water table is very fast, specially during summer seasons rendering the monsoon wells dry. At the onset of monsoon the water table rapidly rises due to recharge.

**2. HARD ROCK AREA**

The ground water in the widely covered Vindhyan Plateau region is primarily under unconfined condition within the secondary porosity of the data formation. However exploratory data indicates that kaimur sandstones found at depths do have enough potentiality at favourable locales. These sandstones after leaching of cementing materials get disintegrated and reduced to silica sands which are loose and act as promising repository of ground water. The lithological characteristics of bore holes have clearly indicated the presence of loose silica sands.

# 2.25.5 Use of Ground Water and Surface Water

The population of Allahabad city is mostly dependent on the ground water for its domestic use. Allahabd Jal Sansthan also draws water from Yamuna river for supply to residential colonies after complete treatment. About 137 MLD ground water is extracted to fulfill the requirement. There are about 147 tube wells in different localities of the city and the Jal Sansthan has provided about 2448 hand pumps to meet the requirement of public, who are unable to get the water connection in their premises. Besides this private boring is also very common. There are two sources of water available at Allahabad, viz., ground water and river water (surface). Both the sources are utilized for drinking water requirement of the city. These water sources are also used for industrial purposes, irrigation purposes and other domestic usage of the city.

# 2.25.6 Ground water availability at study area

**Depth of Ground Water at Allahabad :**

The depth of ground water level in Allahabad city is as follows:

| | | |
|---|---|---|
| - Static Water Table below ground level | - | 25 m |
| - Seasonal Variation | - | 6 m |
| - Head required above ground level for 15 m terminal pressure | - | 28 m |
| - Losses in rising main bends etc. | - | 1 m |
| - Ganga Belt (without casing) | - | 100 – 120’ |
| - Yamuna Belt | - | 130 – 140’ |

- Transport Nagar - 120 – 140’

- Deep Tube wells - 300’

With the rapid rise in population and urbanization the demand for water has also increased and the capacity of surface water purification and supply are limited. The only alternative left is to utilize the ground water. Both the government and public have to depend much on ground water source. This over dependency has although not created any problem at present in ground water table but in future the consequences may be serious. Presently the depletion of the ground water table is of minor nature as informed by Central Ground Water Board. Depth to ground water level, as observed from tube wells constructed down to 255 Meters tapping deeper aquifers, ranges between 6 and 20 Meters below ground water level. The data recorded from National Hydrographs stations reveals that with respect to recharge condition mainly because of rainfall the water table has shown a tendency to rise to the tune of 2.5 M to 3.0 M. Due to the seasonal fluctuation the decline of water table is very fast, specially during summer seasons rendering the monsoon wells dry. At the onset of monsoon the water table rapidly rises due to recharge. The depth of the water table in the study area varies from 6 m to 27 m and the discharge from deep tube wells is available in the range of 10,000-25,000 gallons per hour. Foreseeing the future problems and to create awareness in the public, efforts towards rain water harvesting have also been started. At present arrangement to collect the roof-top rain water at Vikas Bhawan, has been made and after proper screening through a properly designed bed of sand & gravels, is fed into the injection well to recharge the ground water. Construction of another injection well is also planned at the building of Power Grid Corporation, Chauphtka.

The nature of water extraction source in the city is as given below :

| **S.No.** | **Nature of Water Extraction Source** | **Quantity in Nos.** | **Amount of Water Extraction in MLD** |
|---|---|---|---|
| 01. | Deep Tube wells | 147 | 137 |
| 02. | Mini Tube wells | 85 | 25 |
| 03. | Hand Pumps | 2448 | 10 |
| 04. | Yamuna River | - | 80 |

*Overall Status of Water Supply***:**

The total length of distribution pipeline is 1055 Kms. The water supply authorities informed that 100% population is served with water supply during an average supply of 8 hours per day. Normal surface water supply is made available between 5 am and 9 am and 5 pm and 9 pm. However, ground water is supplied for 12 hours a day. There are three zonal service reservoirs which are located at Daraganj, Bhardwaj Ashram and Mayo Hall having capacity of 1.8 ML, 1.35 ML and 2.7 ML respectively. In addition to these three service reservoirs, there are 14 Over Head Tanks (OHTs) which store the water before supply. Unaccounted flow of water is about 30% of total water supply.

## 2.25.7 Ground Water Flow

Water table elevation map prepared with the available data, indicates that ground water flow is towards the river Ganga and Yamuna in the alluvial part. The highest elevation of water table is seen in the extreme northern periphery of the district and exceeds 90 meters above mean sea level. In the proximity of the river Ganga it lies at 80 meters above mean sea level. Within the Doab region, however, a well identified ground water divide exists which trends roughly in a NW-SE direction where the water table elevation varies between 90 and 100 meters above m.s.l.

The behaviour of ground water elevation contours demonstrates that the flow is towards the river Ganga in the north and river Yamuna in the south i.e., both the rivers are effluent in nature. The gradient of water table in the northern part of Ganga river (within the district) is 0.6 meter/Km while in the doab region of the river Ganga and Yamuna it is 0.4 meter/Km. In general, the water table follows the topography. The iso- potentiometric map prepared from the tubewell data indicates that iso-potential line varies from 80 meter above mean sea level in the north to 130 meters above mean sea level in the south of the district. The 80 meter iso-potentiometric line lies in the northern portion trending in NE-SW direction. The higher values of iso-potentiometric lines lie in the southern part covered by Vindhyan formation. They trend NW-SE in the east of Tons river and NEE-SWW in the west of Tons river. The iso-potentiometric lines in the alluvial tract are not governed by the present topography while in the Vindhyan Plateau area they are governed by the ground topography present on date. The region in the south-east of the district falls in down slope direction of ground water flow.

## 2.25.8 Ground Water Resource Potential

Rainfall and the river basins are the main source of ground water in the city. The extent of recharge directly depends upon the intensity of rainfall, topography, vegetation and land use pattern. Ground water resource evaluation conducted reveals the information related to ground water recharge, ground water depth, level of development, and category of the city on the basis of the development.

## 2.25.9 Ground Water Recharge

Depth of water table is highly variable ranging between 4 & 5 meters. Where superficial alluvial cover is encountered depth to water is slightly more than 10 meters. In the hard rock region, in particular, the ground water level remains within 5 meters to between 5 & 10 meters. Such variation of ground water level has relevance to local morphological features. Seasonal fluctuations of water table within the region which are in response to recharge and discharge conditions, is reasonably high and is of the order of 2.5 to 3.0 meters. Generally, the open wells get dried up during summer months creating large scale drinking water crisis.

The objective of the study is to assess the ground water quality in metropolitan city of Allahabad. This includes the study before and after the monsoon season. As the ground water quality in a region depends on a number of factors such as phsiography and soil type, surface and subsurface hydrology, potential of ground water, depth of shallow and deep aquifers, direction of ground water flow etc., data on these aspects has also been collected as described above. Also the quality of ground water depends on point sources like industrial areas, residential areas, petrol pumps and bulk storage of petroleum products, municipal solid waste disposal (landfill) areas, hence the selection of water sampling sites has been done considering the above areas also in mind.

## 2.25.10 Groundwater Survey

**Sampling Locations at Allahabad**

The first round of sampling during pre monsoon season was carried out in February and the second round of sampling during post monsoon season was carried out in September as per the scope of work. Details of the work done are as under:

1) Collection of data related to ground water quality.
2) Selection of water sampling sites.
3) Based on the water demand, Allahabd city is divided into eleven areas and the Allahabad Jal Sansthan has divided the city into four water supply zones for administrative purposes. The names of the zones and number of household connections in each zone are given below :

| Zone No. | Zone | No. of Connection |
|---|---|---|
| 1 | Phaphamau | 15710 |
| 1A | Daraganj | 18358 |
| 2 | Khushrubagh | 47404 |
| 2 | Naini | 3500 |
| Outside Allahabad Nagar Nigam | | 8000 |
| | **Total** | **92972** |

4) Collected 25 nos. of ground water samples from the hand pumps and tube wells covering whole of the city, the locations of which are given in the map of Allahabad city in **Figure – 4.1**. The details of all the hand pumps and tube wells have also been collected which are given in **Table – 4.1**. The samples have been collected covering shallow and deep aquifer regions.
5) The industrial areas, residential areas, municipal solid waste disposal (land fill) area have also been identified and samples collected accordingly.
6) There is no bulk storage depot of Petroleum products in Allahabad city.

**TABLE – 4.1**

**SITE DETAILS OF WATER QUALITY SAMPLING STATIONS OF ALLAHABAD CITY**

| Sampling Location | Depth (Feet) | Area Description |
|---|---|---|
| ***Industrial Area*** | | |
| Tube well Near Market, Naini | 320 – 360 | This tube well is situated in the Industrial area, Naini of Allahabad. The area is situated at the bank of river Ganga. The survey of the region indicates that the area is densely populated by low income group, middle income and high income group people. The agricultural area is also developed. The source of water for domestic and industrial needs is provided by hand pump and tube well. |

| | | |
|---|---|---|
| ***Residential Area*** | | |
| Hand Pump, Gaughat | 40 - 130 | This hand pump is near Erwin Christian College. It is operative since 2003. This area is located at the bank of Yamuna river. The area is famous for its commercial importance. It acts as a road link for joining Allahabad city to Naini/ MP border. This is also one of the ghat of Yamuna river from where pilgrimage all over India take boat and proceed to Sangam/ Ganga for bathing. |
| Hand Pump, Keetganj | 15 - 100 | This hand pump is near the under bridge in Keetganj. This hand pump is operative since 2001. This area is adjacent to Gaughat. The residents of the area mostly belong to low and middle income group . The area is very unhygienic and grazing animals, mostly pigs and street dogs are seen roaming and eating garbage at various locations. |
| Tube well, Daraganj | 330 - 340 | This tube well is on the Bandh road in Daraganj. Daraganj is also located at the bank of river Ganga. The area is densly populated by people of LIG. The source of water contamination could be seepage of water from river Ganga. The municipal solid waste is not properly collected from the collection point which results in further worsening of hygienic conditions of the area. |
| Hand Pump, Bakshi Bandh | 50 - 110 | This hand pump is also located near the river Ganga. The source of the water pollution could be due to seepage of contaminants from river Ganga. The area is dominated by low income group people. |
| Tube well, Phapahamau | 300 - 320 | This tube well is in the Market area. The area is mostly dominated by low and middle income group people. The water quality in this area is more or less satisfactory. |
| Hand Pump, Phaphamau | 40 - 115 | This hand pump is located along the side of the river near the bridge. It is operative since the year 2001. This is the entrance point of river Ganga in Allahabad City, i.e. U/s of Ganga. The surrounding area is cultivated by local people. |
| Hand Pump, Mumfordganj | 15 - 105 | This hand pump is located in the Market area near the house of Shri Anugrah Narain Singh. It is operative since 2001. The area is mostly dominated by middle and high income group of people. The hygienic condition is comparatively better than other area.<br>No known water quality problem has been reported. |
| Hand Pump, Jagram Chauraha | 40 - 120 | This hand pump is near a Primary School. The area is close to the university campus. The area is mostly dominated by students. Commercial activity is also high in the region. |
| Tube well, Civil Lines | 300 - 320 | This tube well is near Yatri Niwas Hotel. This area is located in the heart of the city. This is the important center of commercial activities. This one of the posh colony of the city. Many good hotels are situated here. There may not be any source of water pollution in this region. |
| Tube well, Transport Nagar | 320 - 340 | This tube well is near RTO Office. The area is dominated by commercial activities. |
| Hand Pump, Transport Nagar | 50 - 130 | This hand pump is in the area which is dominated by commercial activities. The area is away from the main city. Most of the transporters have been shifted from heart of the city to this area. |
| Tube well, Rajruppur | 320 - 340 | This tube well is in Kalindi Puram near Jhalwa. The area is mostly dominated by low and middle income group people. The water quality in this area is more or less satisfactory. |

| Sampling Location | Depth (Feet) | Area Description |
|---|---|---|
| Tube well, Karkaraghat | 320 - 340 | This tube well is quite old. The quality of water is satisfactory. |
| Hand Pump, Kareli | 40 - 135 | This hand pump is located in Karelabagh. The area is congested and dominated by mixed population comprising of LIG and MIG. It is located near the river Yamuna. |
| Tube well, Katghar | 340 - 350 | This tube well is located near Yamuna river. The area is very congested and has dense commercial activities. |
| Hand Pump, Zero Road | 40 - 150 | This hand pump is near the Bus Stop. This is also a very busy road due to commercial activities. |
| Hand Pump, Mohtsimganj | 50 - 135 | This hand pump is near the Railway Colony. It is operative since 2001. No known water problem has been reported. |
| Hand Pump, Bairahana | 40 - 115 | This hand pump is near the Police Station. It is operative since 2001. No known water quality problem exists. |
| Hand Pump, Maya Press | 45 - 130 | This hand pump is in the Market. The area is very busy and is located in front of Maya Press which is a renowned publication house. The location of the hand pump is quite unhygienic and hence is not frequently used. |
| Hand Pump, Modern School | 55 - 140 | This hand pump is close to the school campus. The location of this hand pump is very dirty and surrounded by cattle and pigs. The hand pump water is mostly not being used for drinking purpose. |
| Hand Pump, Chowk | 25 - 115 | This hand pump is in the Market near shop of Kashi Ornaments in Rani Mandi. As the name indicates this is located in the heart of the city. This hand pump is operative since 2001. No known problem of water quality exists. |
| Tube well, Mutthiganj | 320 - 340 | This tube well is near Jamuna Christian College. The location of this tube well is near the academic institutes. This area is situated along the bank of river Yamuna. No known problem of water pollution has been reported. |
| Hand Pump, Meerapur | 25 - 105 | This hand pump is in Harshwardhan Nagar. It ahs been operative since 2001. No known problem of water quality exists. |
| ***Landfill Area*** | | |
| Hand Pump, Naini | 45 - 120 | This hand pump is near Petrol Pump near the municipal solid waste disposal site. It is operative since 2001. The hand pump was rebored to get the water. |

Allahabad city is not dominated by industries but there are two identified industrial areas where many large, medium and small scale industries are in operation. These are Naini Industrial area and Teliarganj Industrial Area. The Teliarganj Industrial area is a very small area located in the city and already congested. The new industries have therefore come up in Naini Industrial area. This is a recognized industrial estate away from the main city, located in trans-Yamuna area. The large scale industries are operating only in Naini. There is only one site for disposal of municipal solid waste which is also in Naini. The rest comes under residential area out of which some places are very congested. The intensity of sampling locations is more in residential areas because of the intensity of ground water pumping and close variations in ground water withdrawal from place to place. The quality of ground water is also widely variable in different areas which are in turn varying in quality of recharging source water.

## 2.26 Varanasi

There is an increase in the spurt of industries which in turn also increase the environmental pollution due to emissions and waste generated from these industries. The industrial pollution due to its nature has potential to cause irreversible reactions in the environment and hence, is posing a major threat to sustainable development. As the carrying capacity of the environment is limited and some ecosystems are more susceptible to adverse environmental impacts than others, the unplanned and haphazard location of industries might substantially increase the risk to the environment. The ground water study is essential for assessing the ground water quality. The observational data can be profitably utilized for taking up studies regarding behaviour of ground water table and the pattern of ground water table variations over a number of years, its relation to rainfall and irrigation and latest conditions regarding water table in the State. These studies are of vital importance from the point of view of development of water-logging. Vast area of state of Uttar Pradesh is already water-logged, and any addition to such area is not in the interest of the state. It, therefore, becomes imperative to have a careful watch over the behaviour of ground water table since rise of ground water can be permitted only to a certain extent. The study of behaviour of water table can prove of immense importance in enabling us to act judiciously. Ground water pollution is an impairment of water quality by chemicals, heat or bacteria to a degree that does not necessarily create an actual public health hazard, but does adversely affect such waters for domestic farming, municipal or industrial use. The pollution can originate point or distributed sources within the recharge area of an aquifer. The rise of ground water pollution is highest in urban areas where large volumes of wastes are concentrated into relatively small areas. The risk is further increased if they are located on areas of permeable surface deposits.

Further, the intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and already have resulted in many incidents of ground water contamination. The ground water moves very slowly, sometimes many years may lapse after the start of pollution affected water shows up in a well. Similarly, many years may be required to rehabilitate contaminated aquifers after the sources of pollution have been eliminated. Sometimes this delay may force abandonment of wells and may require costly development of alternate water supplies. Prevention of contamination thus is the best way for protecting ground water quality. Slow movement of ground water is favourable, as radioactive substances, bacteria and viruses may decompose or die, with the passage of time. In such cases, long underground detention times may result in essential removal of the undesired substances. Degradation of ground water quality can take place over large areas from plane or diffused sources like deep percolation from intensively farmed fields or it can be caused by point sources such as septic tanks, garbage disposal sites and oil spills or other accidental entry of pollutants into the underground environment. A third possibility is contamination by line source of poor quality water like seepage from polluted streams.

Ground water is an important component of the water system for domestic, industrial and agricultural purpose. It is commonly used source for drinking water for urban and rural sectors in India. Ground water is a renewable natural resource with a relatively short and shallow circulation with close dependence on precipitation and surface water. Ground water once was supposed to be the hygienic, secure and safe for human consumption. Ground water is now being gradually polluted by human being because of the intense industrial activities. The quality of ground water depends upon the characteristics and type of the sub surface soil and nature of recharge water. Water applied at the ground surface in the form of rainfall and irrigation has to pass through unsaturated zone before leaching the water table. Water in contact with sediment material may result in leaching out of more soluble species, precipitation of saturated species and the formation of colloidal oxides via chemical reactions. The quality of ground water varies from place to place and is primarily governed by the hydrological characteristics of the region.

Today the accelerated pace of development, rapid industrialization and population density have increased demand of water resources. Ground water, a gift of nature, is about 210 billion $m^3$ including recharge through infiltration, seepage and evaporation. Out of this nearly one third is extracted for irrigation, industrial and domestic use, while most of the water is regenerated into rivers. Over 98% of the fresh water on the earth lies below its surface. The remaining 2% is what we see in lakes, rivers, streams and reservoirs. Of the fresh water below the surface, about 90% satisfies the description of ground water, that is, water which occurs in saturated materials below the water table. About 2% water occurs as soil moisture in the unsaturated zone above the water table and is essential for plant growth.

Ground water acts as a reservoir by virtue of large pore space in earth materials, as a conduit which can transport water over long distances and as a mechanical filter which improves water quality by removing suspended solids and bacterial contamination. It is the source of water for wells and springs, that is, the recommended source of rural domestic use. It is replenished by precipitation through rain, snow, sleet and hail. Ground water that can be used annually is about 416 Cu km. which would increase to 1108 Cu km. by 2025 A.D. Today human activities are constantly adding industrial, domestic and agricultural wastes to ground water reservoirs at an alarming rate. Ground water contamination is generally irreversible i.e. once it is contaminated; it is difficult to restore the original water quality of the aquifer. Excessive mineralization of ground water degrades water quality producing an objectionable taste, odour and excessive hardness. Although the soil mantle through which water passes acts as an adsorbent retaining a large part of colloidal and soluble ions with its cation exchange capacity, but ground water is not completely free from the menace of chronic pollution.

It is always better to protect ground water first rather than relying on technology to clean up water from a contaminated source. Ice caps and glaciers account for 76.6% of fresh water source on earth, followed by ground water 22.7% and surface water, a mere 0.5%. Despite ground water being a major source of drinking water it is often disregarded because of a lack of knowledge about its behaviour. Ground water is a principal source of drinking water, particularly in rural areas and also for irrigation, but it has earlier been polluted or overused, making it impotable or resulting in its depletion.

In terms of percentage, the pollution of ground water, is however, quite small. In cities and villages, pollution activities are high and these are affecting human health as well as the environment. Although only a small fraction of the total ground water resources are affected by human activities, but the proportion of local usable resources affected are much higher and becoming critical in some areas close to the major population centers. Developed countries like North America, Europe and Australia are now developing ground water protection policies which would hopefully lead to more sustainable development. The techniques are also available for cleaning up the polluted or contaminated ground water sources, but these are very expensive.

India has a good industrial infrastructure in core industries like metals, chemicals, fertilizers, drugs and petroleum, industries like plastics, pesticides, detergents, fuels, solvents, paints, dyes and food additives, which release effluents and emissions, polluting soil water-plant ecosystem. The disposal of solid and liquid wastes containing heavy metals like lead, nickel, chromium, molybdenum and mercury on land or water bodies, leads to heavy metal contamination of the soil-water-plant-animal ecosystems.

**Factors Affecting Ground Water Pollution :** The extent of ground water pollution depends on the following factors :

1. Rain Fall Pattern,
2. Depth of Water Table,
3. Distance from the Source of Contamination, and
4. Soil Properties such as Texture, Structure and Filtration Rate.

**Source of Contamination in Ground Water :** Underground sources of drinking water, especially in outskirts of larger cities and villages are highly polluted. Ground water is threatened with pollution from the following sources:

3\. Domestic Wastes
4\. Industrial Wastes
3\. Agricultural Wastes
4\. Run off from Urban Areas
5\. Soluble Effluents

**1. Domestic Wastes :** Domestic wastes and methods of their disposal are of primary concern in urban areas. Prime factors responsible for deteriorating the water quality include pathogenic organisms, oxygen demand, nutrients and solids from domestic wastes. Solid wastes are the potential source of contamination as they are partly burned and partly incorporated into the soil and pose serious danger to the ground water.

**2. Industrial Wastes :** Most industries generally produce wastes containing toxic heavy metals along with hazardous organic and inorganic effluents. These chemicals contaminate the ground water and severely pollute it.

**3. Agricultural Wastes :** Fertilizers, pesticides, insecticides, herbicides, processing wastes and animal wastes etc. are constantly added to the water. Leachates from agricultural land containing nitrates, phosphates and potash, move downward with percolating water and join the aquifers below posing danger to the ground water.

Throwing rubbish and other unwanted things into the water are not only the cause of water pollution, but a harmless activity such as farming could lead to some thing as insidious as nitrate pollution.

Rising nitrate levels have raised an alarm because of the possibility of adverse effect on humans and animals. Methaemoglobinaemia or blue baby disease, is caused by the reaction of nitrate with haemoglobin, the oxygen carrier in the blood, producing methaemoglobin, which strangles the oxygen carrying capacity of the tissue. Some claim that nitrate can wear down body's immune system while its derivatives may be carcinogenic. Nitrate also causes eutrophication, although in India and other tropical regions, it is thought that phosphates are more to be blamed for this asphyxiation of water bodies.

**4. Run off from Urban Areas :** Effluents from urban areas contain large concentration of oils, grease, nutrients, heavy metals and detergents. The detergents being soluble can pass through the soil and pollute ground water. Raw sewage dumped in shallow soakpits and seepage from polluted lake, pond or stream also pollute water. Rainfall could pickup substantial contaminants from dust and air and join the aquifer below. The infiltration of liquids containing toxic pollutants may cause pollution in sandy soils and well waters.

Supply of potable water has been affecting the contamination of water resources in most of the developing countries. Rivers, lakes and ground water have been polluted by industrial effluents, pesticides and fertilizers from agricultural runoff and urban waste. Chronic water scarcity is common in areas where ground water has been overdrawn for irrigation, industrial use or to meet the requirements of urban population. Clearing of forests which increase surface runoff and reduce ground water have made the situation worse. Many countries are fast using up their ground water and moving from a situation of crises to disaster.

**5. Soluble Effluents :** Several soluble effluents pollute the ground water critically. The extent of pollution is more in sandy soils and humid regions having high water table conditions. Global withdrawals of water have grown by a factor of over 6 between 1900 and 1995 - more than double the rate of population growth. This is because of increasing water needs for agriculture, industrialization and greater human uses in urban cities. According to WHO, about 460 million people, more than 8 % of the world's population, live in countries that can be considered to be highly water stressed. About 25% of world's population lives in countries where the consumption of fresh water is so high that they are likely to move into situation of serious water stress.

Agriculture takes about 70% of the water withdrawals, often rising to 90% in dry tropics. Water withdrawals for irrigation has increased by more than 60%, which has coincided with the green revolution. High yielding crop varieties require a lot of water. Now water withdrawals are so high that water bodies such as rivers and lakes, have shrunk in size. A direct impact of this has been on the levels of ground water. Increasing use of ground water has pushed the water table lower. This can have serious effects on the flow of rivers, especially during dry periods, which is vital for the aquatic ecosystem. Along the coasts, increasing ground water withdrawals have led to the ingress of saline water into ground water. Other potential sources of ground water contamination are waste water treatment lagoons, mine spills, transport accidents, seepage pits, urban and rural garbages, earthen septic tanks, refuse dumps, barnyard manures, leaching and downward movement of pollutants.

**Harmful Effects of Ground Water Pollution:**

Ground water pollution causes high extent of damage to soil, plants and animals including man.

**Harmful Effects on Man:**

a) Polluted ground water is the major cause for the spread of epidemics and chronic diseases in man. It causes typhoid, jaundice, dysentery, diarrhoea, tuberculosis and hepatitis.
b) Water contaminated by fibres i.e. asbestos causes fatal diseases like asbestosis and lung cancer.
c) Ground water in excessive rainfall areas contain iron in toxic amounts as much as 20 mg/L. In deep tube wells, iron exists as ferrous ion which on taking out rapidly changes to light yellow orange colour due to oxidation and precipitation as ferric hydroxide.
d) The woollen industries contribute large amounts of toxic metals such as Hg, Ni, Cu, Cr, Fe, and cyanides to ground water causing skin and stomach diseases in man.

**Harmful Effects On Soil:**

a) The use of polluted ground water for irrigating agricultural fields severely damages crop and decreases grain production.
b) Polluted water acutely affects soil fertility by killing bacteria and soil microorganisms.
c) Contaminated ground water increases alkalinity in the soils.
d) Ground water pollution affects plant metabolism severely and disturbs the whole ecosystem.**Table - 1.1** shows the occurrence of ground water pollution in India and the problematic pollutants in groundwater quality in major cities in UP.

### TABLE – 1.1GROUND WATER POLLUTION IN INDIA

| Pollutant | State | Place of Occurrences |
|---|---|---|
| Salinity (Inland) | Maharashtra | Amravati, Akola |
| | Bihar | Begusarai |
| | Haryana | Karnal |
| | Rajasthan | Barmer, Jaisalmer, Bharatpur, Jaipur, Nagaur, Jalore & Sirohi |
| | U.P. | Mathura |
| Salinity (Coastal) | Andhra Pradesh | Vishakapatnam |
| | Orissa | Puri, Cuttak, Balasore |
| | West Bengal | Haldai & 24 Pargana |
| | Gujarat | Junagarh, Kachch, Varahi, Banskanta & Surat |
| Fluoride | Kerala | Palaghat Krishna, Ananipur, Nellor, Chittoor. |
| | Andhra Pradesh | Cuddapah, Guntur and Nalgonda |
| | Gujarat | Banskanta, Kachch & Amreli |
| | Haryana | Hissar, Kaithal & Gurgaon |
| | Orissa | Bolangir, Bijapur, Bhubaneshwar and Kalahandi |
| | Punjab | Amritsar, Bhatinda, Faridkot, Ludhiana & Sangrur |
| | Rajasthan | Nagaur, Pali, Sirohi, Ajmer & Bikaner |
| | Tamil Nadu | Chengalput, Madurai |
| | U.P. | Unnao, Agra, Aligarh, Mathura, Ghaziabad, Meerut & Rai Baraili |
| Sulphide | Orissa | Balasore, Cuttak & Puri |
| Iron | U.P. | Mirjapur |
| | Assam | Darrang, Jorhat, Kamrup |
| | Orissa | Bhubaneshwar |
| | Bihar | E. Champaran, Muzaffarpur, Gaya, Manger, Deoghar & Madubani |
| | Rajasthan | Bikaner, Alwar, Bharatpur |
| | Tripura | Dharmnagar, Kailasanar, Ambasa, Amarpur & Agartala |
| | West Bengal | Madnipur, Howrah, Hoogly and Bankura |
| Manganese | Orissa | Bhubaneshwar, Athgaon |
| | U.P | Muradabad, Basti, Rampur & Unnao |
| Arsenic | West Bengal | Malda, Murshidabad, Nadia, 24 Pargana |
| Nitrate | Bihar | Patna, East Champaran, Palamu, Gaya, Nalanda, Nawada and Banka |
| | Andhra Pradesh | Vishakapatnam, East Godvari, Krishna, Prakasam, Nellor, Chittoor, Anantpur, Cuddapah, Kurnool, Khamam and Nalgonda |
| | Delhi | Naraina, Shehadr (Blocks) |
| | Haryana | Ambala, Sonepat, Jind, Gurgaon, Faridabad & Hissar |
| | Himachal Pradesh | Kulu, Solan, Una |
| | Karnataka | Bidar, Gulbarge and Bijapur |
| | Madhya Pradesh | Sehore, Bhopal & (West & Central Part of state) |
| | Maharashtra | Jalna, Beed Nanded, Latur, Osmanabad, Solapur Satara, Sangli and Kolhapur |
| | Punjab | Patiala, Faridkot, Firozpur, Sangrur & Bhatinda |
| | Rajasthan | Jaipur, Churu, Ganganagar, Bikaner, Jalore, Barmer, Bundi and Sawaimadhopur |
| | Tamil Nadu | Coimbatore, Penyar and Salem |
| | West Bengal | Uttar Dinajpur, Malda, Birbhum, Murshidabad, Nadia, Bankura and Purulia. |
| Chloride | Karnataka | Dharwad, Belgaum |
| | Madhya Pradesh | Bhind, Shagapur and Sehore |
| | Maharashtra | Solapur, Satara, Amravati, Akola & Buldana |
| | Rajasthan | Barmer, Jaisalmer, Jodhpur & Jalore |
| | West Bengal | Contai, Digha, Haldia |
| Zinc | Andhra Pradesh | Hyderabad, Osmania University campus |
| | Delhi | R.K. Puram |
| | Rajasthan | Udaipur |
| Chromium | Punjab | Ludhiana |

The available ground water resources of Uttar Pradesh are given in **Table - 1.2** below:

**TABLE - 1.2**

**GROUND WATER RESOURCES OF UTTAR PRADESH**

| S.N. | State | Total Reple-nishable Ground Water Resource (MCM/Yr) | Provision for Domestic Industrial and other uses (MCM/Yr) | Available Ground water for irrigation resource in net terms (MCM/Yr) | Net Draft (1993) (MCM/Yr) | Balance Ground water resources for future use (MCM/Yr) | Level of ground water develop-ment' (%) | Utilisable irrigation potential for land develop-ment (Mha) |
|---|---|---|---|---|---|---|---|---|
| 1 | Uttar Pradesh | 83820.85 | 12573.13 | 71247.72 | 26835.28 | 44412.44 | 37.66 | 16.79896 |
| Source: Ground Water Statistics 1996, Central Ground Water Board, MCM : Million Cubic Metres | | | | | | | | |

**OBJECTIVES OF STUDY:**

More than 90% of rural population uses ground water for domestic purpose. It is therefore extremely important to have detailed information and knowledge about the quality of ground water. Keeping this in view Central Pollution Control Board, New Delhi has assigned the project on "Assessment of Ground Water Quality of Metro City - Varanasi” to Pollution Control Research Institute (PCRI), BHEL, Haridwar with the following objectives:

1. **Assessment of Ground Water Quality during pre monsoon period located at**

INDUSTRIAL AREA, RESIDENTIAL AREA, SANITARY LANDFILL AREA, PETROL, DEPO/ADJOINING AREAS for ground water.

1. **Assessment of Ground Water Quality during post monsoon period located at**

INDUSTRIAL AREA, RESIDENTIAL AREA, SANITARY LANDFILL AREA, PETROL, DEPO/ADJOINING AREAS for ground water.

# 2.26.1 DESCRIPTION OF STUDY AREA

Varanasi district forms part of central Ganga plain and is situated in the south west part of U.P. State. Physiographically the district can be divided into two physical regions, i.e., the northern alluvial plain and the southern plateau area. The northern alluvial plain is drained by the Ganga and its tributaries namely the Gomti and the Varuna rivers. The southern plateau comprising of extensive hillocks and mesas of Vindhyan sandstone and shales, is deeply dissected by the Karamnasa river and its effluents. The eternal and ancient city of Varanasi is a religious place on the bank of the Holiest Indian river Ganga. It is a magnificent city with myriad attractions both as an exalted place of pilgrimage and micro centre of faith. It is one of the most important places of pilgrimages for Hindu and Buddhists in the world. It is a unique city where the past and the present, eternity and continuity live side by side. The city rises through the High northern bank on the outside curve of Ganga to form a magnificent panorama of buildings in many varieties of Indian architecture. The unique relationship between the city and sacred river is the essence of ‘Varanasi - the land of Sacred Light’. Glorified by myth and legend and sanctified by religion, it has always attracted a large number of pilgrims and being worshipped from times immemorial.

The district Varanasi is located in south west portion of Uttar Pradesh and having the geographical coordinates as 82º 15’ to 83º 30’ East longitude and 24º 35’ to 25º 30’ North latitude. The district of Varanasi is surrounded by Jaunpur and Ghazipur districts in the north, Mirzapur district in the south, Bhadohi district in the west and Sahabad district of Bihar State in the eastern side. The geographical area of the district is 4035 Sq. Km. Administratively the district is divided into four tehsils, namely - Varanasi, Sakaldiha, Chandauli and Chakia which have been further sub-divided into twenty two development blocks. Varanasi is the largest Tehsil of the district occupying 35.9% of area and smallest is Chandauli which is having 15.5% share in the total area of the district. The district is having 2969 villages and 17 towns, as per 1991 census. Geographically, it can be divided into two parts, first portion comes under Gangetic plain and another is Naugarh’s hilly terrain. The holy river Ganga divides the district into almost two equal parts and other rivers flowing through the districts area Gomti, Karamnasa, Chandra Prabha and Varuna. Karamnasa practically separates the district from the surrounding Bihar state. The district is well connected by National and State Highways and also by a network of railways. The National Highway nos. 2 and 7 pass through the district in the east-west and north-south directions, respectively.

The Varanasi city is located in the North Eastern part of the Nation and is one of the biggest cities of Uttar Pradesh and is the district headquarters **(Figure– 2.1)**. The geographical coordinates of the city are 25º 0’ to 25º 16’ North latitude and 82º 5’ to 83º 1’ East longitude. It is bounded on north by Jaunpur and Ghazipur, on south east by Mughal Sarai, on east by Bihar State, on west by Bhadohi and on south by Mirzapur. The area of the city is 78.5 Sq. Km. The Varanasi Nagar Nigam has divided the area of the city in 90 wards for administrative and management purposes. Apart from being a place of pilgrimage and tourist centre, Varanasi is a fast growing commercial, industrial and trading centre of Uttar Pradesh and Central India. It is well connected with all metro cities and other major cities of the country by Railways, National Highways and Airlines.

The general information about Varanasi is as given below:

| S.N. | INFORMATION | DATA |
|---|---|---|
| 01. | Population | ~ 14 lacs as per 2001 Census |
| 02. | Area | 78.5 sq.kms |
| 03. | Altitude | 80 meters above sea level |
| 04. | Temperature Summer | 22.6 to 41.5 °C |
| 05. | Temperature Winter | 9.5 to 23.4 °C |
| 06. | Rainfall | 1113.4 mm |
| 07. | Language | Hindi, Urdu & English |

Varanasi Jal Sansthan provides the existing water supply in the city. With the development of many new residential areas and increase in population, the water demand has increased. The surface water supply is not adequate to meet this increased demand. The drinking water supply is drawn from surface and ground water. The city is divided into two parts, viz., cis-Varuna area and the trans-Varuna area. The cis-Varuna area has a mixed supply of water, that is, from both surface and ground water, whereas in trans-Varuna area the water supply is exclusively from ground water. The source of surface water is river Ganga. Deep tube wells, hand pumps and private bore wells are the main sources for extraction of ground water in the city to cater to the water demand of the population. The depth of ground water varies from 3.02.to 15.25 m in various parts of the city. Apart from municipal sources of water supply, a large number of consumers also have shallow hand pumps for augmenting their water requirements.


**Figure – 2.1 ; Map of Varanasi City**

## 2.26.2 Physiography

The district is picturesquely placed on both sides of the Ganga river. The northern part of it is alluvial plain while the southern part is having hilly tracts of projecting mountainous ranges of Vindhyas. The district is made up of two natural divisions, namely the plain under the Ganga and its tributaries and the plateau area of Naugarh development block of Chakia tehsil which has mountainous ridges overcast with dense forests and deep valleys drenched with rushing streams. The river system consists of two important rivers - the mighty Ganga, highly revered by Hindus since ages and its main tributary Gomti. Varuna, Asi Banganga, Chandra Prabha and Karamnasa are other important tributaries of the Ganga that drain the area. The surface of Chandauli tehsil is comparatively low which causes water logging problem during rainy season. The soil of the hilly-tract is hard and of red colour. In some places pieces of alkaline land is also found but a major part of Chandauli tehsil has black soil.

The total area under forest in the district is 77404 hectares and almost ninety-nine percent of it is found in Naugarh development block of Chakia tehsil. The forest land of Varanasi is bounded by Chandauli in North, Bihar State in East, Mirzapur in South and Narayanpur-Ahraura, Robert ganj-Chopan highways in West. Geographically it is a hilly area and located in between Kymore and Vindhyan hills. The forests are dense and mainly of the tropical dry mixed deciduous type having varying growth depending upon the nature of the soil and moisture. There are forests on ridges, flat hill tops, foot of the hills but the trees found in this region are generally of poor quality. Salai, Piar, Mahua, Tendu apart from usual type of species of trees are found here. Dry Sal and green vegetation generally occur on the plateau region while *Bosewellia* type of jungle is found on the flat tops of the hill. *Dhak* jungle is also found in plain area of the district.

The forest area mostly belonged to erstwhile Banaras princely State which is presently under the charge of U.P. Forest Department. *Banarsi langra* a mango delicacy and yellowish betel leaves (Banarsi Pan) grown in the district are famous throughout the country. Physiographically Varanasi district may be divided into two physical regions – (1) the northern alluvial plain and (2) the southern hilly regions (plateau).

The plain is devoid of rock and made up entirely of alluvium of two types, the newer alluvium being the base of the flood plain of the Ganga and the older is that of the level upland (locally known as uparwar). The two are separated by clearly defined banks of varying heights which mark the extreme flood limit of the river. Apart from this difference, there are local variations depending upon the slope and height. The northern alluvial plain is generally a flat land with east or north-eastward slopes on a regional scale and forms a part of the central Ganga plain.

The southern hilly region, being a part of Vindhyan plateau is not uniform. It rises abruptly on the southern boundary of the alluvial tract with an escarpment, the average elevation being between 305 metre and 366 metre above mean sea level. The undulating table land extends between parallel ranges of hills and valleys. It is intersected every where by low ridges which are drained by torrential rains. The ridges are scarped and precipitous with long and tortuous gorges. The river Chandra Prabha escapes through these gorges by a single leap and the river Karamnasa by succession of cascades. A number of isolated hills stand out above the scarp. The general direction of the hills, which are not high, is east-west but there are numerous cross ranges which are rugged.

The area occupied by alluvium can be delineated all along Ganga and Gomti, draining all the blocks of the district, except Chakia block. Further the younger alluvium is confined dominantly within the flood plain of these rivers. The flood plain can be further differentiated into two geomorphic units – (1) Younger flood plain (2) Older food plain.

(1) *Younger Food Plain :* The river channel and its adjacent areas forming terraces which are subjected to periodic floods, consist of sand, silt and silty sand with minor clays and form the flood plain of the rivers. This is a narrow zone along the river channel and subjected to flooding regularly during rainy season.
(2) *Older Flood Plain :* Older flood plain of the river Ganga and Varuna can be delineated extending to few kilometers and is locally termed as khadar. The older flood plain is more conspicuous and wide in the eastern bank as compared to western side.

The soils in the district are classified into two broad groups, alluvial and residual, representing the different stages of soil development resulting from a sub humid to a humid climate and the physical and chemical weathering of the soils. The alluvial group, comprising the greater and the more important portion of the district - the tehsils of Chandauli and Varanasi, possesses soils developed from the alluviums of the Ganga, while the residual group comprising an area of less importance - tehsil Chakia, primarily possesses residual soils developed insitu from the Vindhyan rocks. The groups are inherently and genetically different in nature. Agriculturally also, they behave differently, the alluvial soils being very productive and the soils of the Vindhyan System supporting only sparse cultivation.

## 2.26.3 Climate

The Varanasi district falls in the subtropical region and its climate is classified as tropical to subtropical type, characterized by hot summer and severe winter. The district experiences three distinct seasons namely, summer, rainy and winter. Winter usually commences from middle of November and extends till end of February whereas summer starts from April and extends upto the middle of June. March is a transitional period. The rainy season starts normally by the third week of June and continues till September or early part of October.

The climate of Varanasi district is more or less dry. May and June are the hottest months of the year. Dust storms and hot waves are common during summers. The maximum temperature in winter is recorded to be 23.4 ºC and the minimum is 9.5 ºC. Winter starts from mid of November. The most chilling months are December and January. At times, when the area is under the grip of cold wave due to sweeping cold winds of northern Himalayas, the temperature drops to as low as freezing point in the plains. In general, the climatic conditions are beneficial to health. The maximum temperature in the summer is recorded as 41.5 ºC and the minimum is reported to be 22.6 ºC. The average normal maximum temperature has been observed as 41.5ºC during June and minimum 9.5ºC during January. The relative humidity varies from month to month being maximum of 82% during the month of August, in the period of south west monsoon and minimum of 28% during the month of April. It therefore varies from 28% in dry season to 82% during the rainy season. The mean monthly relative humidity is 55.75%. The district receives greater part of the annual rainfall through south west monsoon between July and September. The average normal rainfall of the city is varied from min 3.3 mm to the highest of1113.4 mm.

## 2.26.4 Hydrogeology

Ground water occurs in both, the Kaimur sandstone and the unconsolidated alluvial sediments in the district. In the Kaimur sandstone (Vindhyans), the occurrence and movement of ground water is controlled by the size, depth, spacing and degree of intercalated planes of weakness i.e. joints, bedding, fractures and fissures. The availability of ground water in a well depends upon encountering the number of such plane of weakness and the extent of weathering in them. Generally the ground water occurs under water table condition.

In the unconsolidated alluvial sediments ground water occurs in the pore spaces in the zone of saturation. The ground water in the unconsolidated deposits of the older alluvium in the area comprises of two bodies, (i) a shallow ground water body which occurs principally in clay and kankar beds of back swamp deposits and (ii) deep or main ground water body which occurs in thick sands of the meander belt deposits. These two water bodies are hydraulically distinct. The back swamp deposits are thick but are likely to be inter connected when they are comparatively thin. The shallow ground water in back swap deposits is generally unconfined and its static water level is only few meters bgl. It supplies water to the dug wells. The deep ground water body in meander belt deposits is considered to be hydraulically continuous and is confined in nature. It supplies water to the tube wells for irrigation, industrial, and domestic uses.

The back swamps deposits and the meander belt deposits differ considerably in their capacity to absorb and transmit water to the zone of saturation. The back swamp clays are massive and contain Kankar and in thin lenses of fine grained sand. Because this material is generally too fine grained to transmit water readily, it prevents the downward percolation of water from the land surface and also confines water in the underlying meander belt sand deposits. The meander belt deposits consist of medium to coarse grained sand and underlying impervious back swamp clays, are moderately to highly permeable and constitute a potential ground water reservoir.

The drainage system of the area is controlled by the river Ganga and its tributaries. The river Ganga flows in the east or north-eastern direction along the north-eastern and south western boundaries of the district. The Ganga touches the district at the village Betabar where it is joined by a small stream known as Subbha Nullah, which drains a small area. For a distance of about 11.2 kiloimeters the river separates Varanasi form Mirzapur and then runs roughly north-eastwards across the district to the point where it is joined by the river Gomti. In the early part of its course through the district, it separates the town of Amanat which is on the left bank from the towns of Ralhupur and Ramnagar which are on right bank. The right bank is high and the left bank is steep. After leaving the town of Ramnagar the river flows through the city of Varanasi which is situated on its left bank and rises into a high ridge after the confluence of the Assi with the Ganga. On the right bank there lies an extensive expanse of sand which has accumulated between the river and the high flood bank. After leaving the Malviya bridge the river is joined by the Varuna at Sarai Mohan and continues in an easterly direction beyond the confluence. The river flows in a northerly direction and throughout its stretch, the right bank constitutes a high ridge of kankar. As is generally the case along the Ganga, the banks are alternately steep and shelving , the precipitous bank on one side of the river being faced by a gentle slope of alluvium on the other. The velocity of the Ganga in this district varies from less than 3.2 kms/hour in the dry weather to about 8 kms/hour in the rains, the average maximum rise of the river during the ordinary floods being about 11.58 meters. The biggest tributary of the Ganga in the district is the Gomti, which maintains south-east trend. This river meanders a lot and this fact might have given rise to its name. The banks are alternately abrupt and sloping, the convex side being mostly low and shelving with broad stretches of alluvial and cultivable land.

## 2.26.5 Use of Groundwater and Surface Water

The population of Varanasi city and in particular of Trans Varuna area is mostly dependent on the ground water for its domestic use. Varanasi Jal Sansthan also draws water from Ganga river for supply to residential colonies after complete treatment. About 115 MLD ground water is extracted to fulfill the requirement. There are about 111 tube wells in different localities of the city and the Jal Sansthan has provided about 1954 hand pumps to meet the requirement of public, who are unable to get the water connection in their premises. Besides this private boring is also very common.

There are two sources of water available at Varanasi, viz., ground water and river water (surface). Both the sources are utilized for drinking water requirement of the city. These water sources are also used for industrial purposes, irrigation purposes and other domestic usage of the city.

## 2.26.6 Ground water availability at study area

Ground water is one of the earth's most widely distributed resource and is most important because of the physiological needs of man, animal and vegetation kingdoms. This valuable resource not only supports life on the earth but also governs the economic, industrial and agricultural growth of human civilization. More than 45% of the total irrigation in our country depends on ground water resource. Nearly 80% of the extracted ground water is being utilized for irrigational purposes in the state of Uttar Pradesh.

Since the monsoon is unpredictable and the deficit causes sometimes drought conditions, it has become imperative for the planners to look forward for a dependable source of water supply, i.e. ground water which is an assured source for agricultural, industrial and domestic requirements.

The depth of ground water level in Varanasi city is as follows :

| | | |
|---|---|---|
| - Static Water Table below ground level | - | 16 m |
| - Seasonal Variation | - | 6 m |
| - Head required above ground level for 15 m terminal pressure | - | 20 m |
| - Losses in rising main bends etc. | - | 1 m |
| - Shallow aquifers | - | 55' |
| - Deep Tube wells | - | 100 - 200' |

With the rapid rise in population and urbanization the demand for water has also increased and the capacity of surface water purification and supply are limited. The only alternative left is to utilize the ground water. Both the government and public have to depend much on ground water source. This over dependency has although not created any problem at present in ground water table but in future the consequences may be serious. Presently the depletion of the ground water table is of minor nature as informed by Central Ground Water Board. But as of recently, because of exhaustive drawing of water from deep tube wells in the absence of other alternative, yield of many of the tube wells has come down drastically, and for many reboring has become necessary. It therefore implies that the availability of ground water is reducing day by day. Data collected from twenty eight National Hydrograph Stations of C.G.W.B. and dug wells monitored in the year 1996 in May indicated that water level varies from 3.02 to 15.25 m bgl in the alluvial area of the district. It is further seen that water level is generally deeper in the areas adjacent to the rivers Ganga and Karmanasa, whereas it is shallower in the areas of heavy canal irrigation.

The depth of water in the plateau area varies between 9.38 and 14.05 m bgl. The data for the period Nov. 1996 indicates that water level in the alluvial area varies between 1.38 and 11.72 m bgl and in the plateau area it varies from 3.78 to 8.64 m bgl. The deepest water level of 15.25 m bgl has been observed in the western part of the district in the Sevapuri Block, whereas the shallowest is noted in the central part, i.e., 3.03 m bgl in Niamatabad Block at Mughal Sarai, in pre monsoon period, whereas it varies between 11.72 and 1.38 m bgl respectively, in post monsoon period. The Post monsoon (Nov. 1996) depth to water level map, on perusal gives an identical picture as seen in the pre monsoon, i.e. the deep water levels being confined to areas close to river banks. The water level varies from 2.77 to 10.22 m bgl close to bank of Ganga whereas in pre monsoon it varies between 4.21 and 9.73 m bgl.

On a regional scale, a single aquifer system is seen extending down to 149 m bgl. The thickness of the productive aquifer varies from 40 to 90 m. The aquifer is semiconfined to unconfined in nature. The sediments are fine to coarse sand. The productive aquifer extends down to 282 m bgl touching the bed rock shale at 293 m bgl. The total thickness of the productive aquifer lies between 27 and 282 m. The piezometric head varies from 9 to 19 m bgl and the discharge of the tube wells varies from 2270 to 3950 litres/minute.

The nature of water extraction source in the city is as given below :

| **S.No.** | **Nature of Water Extraction Source** | **Quantity in Nos.** | **Amount of Water Extraction in MLD** |
|---|---|---|---|
| 01. | Deep Tube wells | 111 | 115 |
| 02. | Hand Pumps | 1954 | 9 |
| 03. | Ganga River | - | 125 |

*Overall Status of Water Supply*

The total length of distribution pipeline is 568 Kms. Presently water is being supplied @ 171 litres per capita per day only against the demand of 200 lpcd. As per the requirement of 200 lpcd, 280 MLD of potable water is to be supplied. However, as per the Varanasi Jal Sansthan, if power is made available continuously, 270 MLD of water is being supplied. Thus a shortfall of 10 MLD still exists. The water supply authorities informed that 100% population is served with water supply during an average supply of 8 hours per day. Normal surface water supply is made available between 5 am and 9 am and 5 pm and 9 pm.

However, ground water is supplied for 12 hours a day. There are four zonal service reservoirs and three reservoirs situated at Bhelupur Water Treatment Works. In addition to these seven service reservoirs, there are 17 Over Head Tanks (OHTs) which store the water before supply.

## 2.26.7 Ground Water Flow

The water level data of permanent hydrograph stations of C.G.W.B. of Varanasi district of May, 1996 indicates that the water table elevation varies from 270 m in the extreme south to 70 m amsl in the north. The master slope of the water table is from South to North, and is towards the river Ganga indicating that the river Ganga is effluent in nature. In the central and eastern parts of the district water table contours are widely spaced showing that the aquifer is good in permeability. The western part of the district shows a ground water mound and at places the close spacing of the water table contours reflects moderately poor permeability of the aquifer. In the plateau area in the south of the Ganga, the water table contours are very closely spaced showing poor permeability of the aquifer. The post monsoon (Nov. 1996) water table elevation map shows an identical picture with that of the pre monsoon water table elevation map. The moderately poor permeability of aquifer is confined in the western part of the district as the water table elevation contours are further closely spaced. In the southern part of the district also, the very close spacing of water table elevation contours confirms the poor permeability of the aquifer.

On the basis of water table elevation map data, the following interferences have been drawn :

1. Ground water flows from south to north following the general drainage pattern.
2. The sediments are more permeable in the central part of the district.
3. River Ganga is effluent in major part of the district.

*Seasonal Fluctuation :* Fluctuation of water table depends on the following factors :

1. Replenishable recharge from rainfall.
2. Seepage from surface water bodies.
3. Inputs to ground water body by applied irrigation.
4. Losses due to evapotranspiration.
5. Discharge from ground water extraction structures.
6. Ground water movement.

Annual seasonal fluctuation of water level has been determined from the pre monsoon and post monsoon water level data. It is observed that the maximum rise of water level is present in the southern part of the district covering almost 90% of Naugarh block. Rise in water level, due to the south west monsoon, is seen only in the areas, in the flood plain of Ganga, Gomti and Karamnasa in the western, southern and south-eastern parts of the district. In the eastern part of the district, a small area in Dhanapur block, a decline, i.e. more than 3 m bgl in water level has been observed. The decline in water level is also seen in Chahnian block, i.e. less than one m bgl and in Arazi Lines block in the extreme south, the decline is observed, which is very less, i.e. 0.08 m bgl.

The declining trend is due to over exploitation of ground water resources whereas the rising trend is seen due to non development/under development of ground water for irrigation and the presence of vast uncultivated area in the older flood plain.

## 2.26.8 Groundwater resource potential

Estimation of ground water recharge precipitation being the principal source of groundwater recharge in the district, the quantum relates directly to the intensity of rainfall, nature of soils and its textural characteristics, local vegetation cover and land use pattern. Rainfall and the river Ganga basin are the main source of ground water in the city. The extent of recharge directly depends upon the intensity of rainfall, topography, vegetation and land use pattern. Ground water resource evaluation conducted reveals the information related to ground water recharge, ground water depth, level of development, and category of the city on the basis of the development. The exploitable dynamic ground water resource is estimated to be 1172.46 mcm and the ground water draft is estimated to be 671.87 mcm. The balance of 500.59 mcm of ground water is available for future development both for domestic and irrigation purposes. Thus ground water draft is the quantity of ground water withdrawn from the ground water reservoir.

## 2.26.9 Ground Water Recharge

The replenishable recharge is estimated based on pre monsoon (May/June) to post monsoon (October/November) water level fluctuation. The major part of ground water resource estimation is based on ground water fluctuation data generated by observations carried out on strengthened network of hydrograph stations regularly. The annual replenishable ground water recharge includes the above recharge components except the potential recharge. The total ground water recharge for water table (unconfined) aquifer is taken as annual replenishable ground water recharge plus potential recharge in shallow water table zone, which would be available for utilization for irrigation, domestic, industrial and other uses. As per the recommendations, 15% of total ground water resource is to be kept for domestic, industrial and other purposes. The remaining 85% is for irrigation use.

The objective of the study is to assess the ground water quality in metropolitan city of Varanasi. This includes the study before and after the monsoon season. As the ground water quality in a region depends on a number of factors such as physiography and soil type, surface and subsurface hydrology, potential of ground water, depth of shallow and deep aquifers, direction of ground water flow etc., data on these aspects has also been collected as described above. Also the quality of ground water depends on point sources like industrial areas, residential areas, petrol pumps and bulk storage of petroleum products, municipal solid waste disposal (landfill) areas, hence the selection of water sampling sites has been done considering the above areas also in mind.

## 2.26.10 Sampling Locations at Varanasi

The first round of sampling during pre monsoon season was carried out in February and the second round of sampling during post monsoon season was carried out in September as per the scope of work. Details of the work done are as under:

- Collection of data related to ground water quality.

- Selection of water sampling sites.

- Based on the water demand, Varanasi city is divided into eleven zones or wards by Varanasi Jal Sansthan for distribution of water. These are namely Bhelupur, Sigra, Chowk, Benia, Cotton Mill, London Mission, Lahartara, Rajghat, Maldahia, Jaitpura and Lanka. The total storage capacity of all the reservoirs is 79.8 million litres. The storage capacity of zonal reservoirs is 12.0 million litres, of reservoirs situated at Bhelupur is 50.0 million litres and of overhead tanks it is 17.8 million litres.

- Banaras Hindu University (BHU) and Diesel Locomotive Works (DLW) have their own water supply network.

- The details of water connections in Varanasi city are as given below :

| | | |
|---|---|---|
| Total Number of Connections | - | 109428 |
| (a) Domestic (Metered) | - | 79182 |
| (b) Domestic (Non-metered) | - | 27100 |
| (c) Non Domestic | - | 3146 |
| Others | | |
| (a) Public Taps | - | 1402 |
| (b) Hand Pumps | - | 1954 |

- Collected 25 nos. of ground water samples from the hand pumps and tube wells covering whole of the city, the locations of which are given in the map of Varanasi city in **Figure – 4.1**. The details of all the hand pumps and tube wells have also been collected which are given in **Table – 4.1**. The samples have been collected covering shallow and deep aquifer regions.


**Figure – 2.1: Location Map showing GWQ sampling location of Varanasi City**

**TABLE – 4.1**

**SITE DETAILS OF WATER QUALITY SAMPLING STATIONS OF VARANASI CITY**

| Sampling Location | Depth (Feet) | Area Description |
|---|---|---|
| ***Industrial Area*** | | |
| Hand Pump, Ram Nagar | 80 - 100 | This hand pump is in the Sabzi Mandi area on Kila Road. It is in trans Yamuna area. Ramnagar is an industrial estate of Varanasi city which has come up from 1975 onwards. The area is situated near the bank of river Ganga. The area is densely populated by low income group, middle income and high income group people. The agricultural area is also developed. The source of water for domestic and industrial needs is provided by hand pump and tube well. The quality of water is reported to be satisfactory. |
| Tube well, Munduadih | 70 - 80 | This tube well is near the Police Station in Munduadih. This is an industrial area having lot of commercial activities. The tube well is operative since 1997 and the water quality is reported to be satisfactory. |
| Hand Pump, Chandpur | 70 - 80 | This hand pump is on the Chandpur Chauraha near the state highway. The hand pump is operative since 2001. A lot of industries have come up in the area which may be contribute to pollute the ground water. |
| ***Residential Area*** | | |
| Tube well, BHU (Lanka) | 200- 220 | This tube well is near Bhogabir Tanki in BHU (Lanka) area. It is a new tube well operative since 2003. The area is famous for its educational importance and a new Vishwanath temple. No known water quality problem exists.. |
| Hand Pump, Sonarpura | 80 - 100 | This hand pump is near Radhika Silk Emporium, near Kedar Ghat/Kedar Temple chauraha. This hand pump is operative since 2001. The residents of the area mostly belong to low and middle income group . |
| Tube well, Gadauliya | 350 - 400 | This tube well is near Dashashumedh Police Station. The area is very congested and densely populated by people of LIG and MIG. The source of water contamination could be seepage of water from river Ganga. |
| Tube well, Benia No. 3 | 40 - 50 | This tube well is near Raj Narain Smarak Park and is also located near the river Ganga. The depth of the water level is quite shallow in this area. The source of the water pollution could be due to seepage of contaminants from river Ganga. The area is dominated by low income group people. |
| Hand Pump, Ram Katora | 40 - 50 | This hand pump is in the Market area near Banaras Auto Scooters near Gautam Hotel. The area is mostly dominated by low and middle income group people. The water quality in this area is more or less satisfactory. |
| Tube well, Nati Imli No. 1 | 80 - 100 | This tube well is near Bharat Milap Spot. It is operative since the year 1993. It is a congested area inhabited by LIG and MIG people. The water quality is more or less satisfactory. |

| | | |
|---|---|---|
| Tube well, Bari Bazar | 80 - 100 | This tube well is near Chaukaghat Pani Ki Tanki and is quite old. The area is mostly dominated by low, middle and high income group of people. The hygienic condition is comparatively better than other area. No known water quality problem has been reported. |
| Hand Pump, Peeli Kothi | 40 - 50 | This hand pump is in front of Jamia Hospital and is near HP Petrol Pump of S.P. Varma & Co. The area is having lot of commercial activities. The water quality does not seem to be affected by adjacent Petrol Pump. |
| Tube well, Bhelupur | 80 - 100 | This tube well is near Varanasi Jal Sansthan Parisar. This area is located in the heart of the city. This is the important center of commercial activities. There may not be any source of water pollution in this region. |
| Tube well, Nadesar | 130 - 150 | This tube well is near Charan Nagar, Dhobi Ghat and Mint House. This is a residential area and is also dominated by commercial activities. |

| **Sampling Location** | **Depth (Feet)** | **Area Description** |
|---|---|---|
| Tube well, Bhojubir | 80 - 100 | This tube well is near U.P. College. The area is mostly dominated by students. Commercial activity is also high in the region. There is no reported water quality problem in the area. |
| Tube well, Shivpur | 80 - 100 | This tube well is near Normal School, Kadipur and Mehta Nagar. The BHEL complex is also situated in this area. This area is also slightly away from the main city. The area is mostly dominated by low and middle income group people. The water quality in this area is more or less satisfactory. |
| Tube well, Basai | 600 - 700 | This tube well is near Gyanodaya Balika Vidyalaya Board in Nawalpur and is quite old. This is a deep tube well and the depth of water level is very high. The quality of water is satisfactory. |
| Hand Pump, Paharia | 100 - 120 | This hand pump is located near Paharia Chauraha. The area is congested and dominated by mixed population comprising of LIG and MIG. No known water quality problem exists. |
| Tube well, Sarnath | 130 - 150 | This tube well is near Shiv Mandir in Sarnath. This is a religious place for Buddhists and Hindus. A number of people make silk sarees in this locality. Sarnath is about 10 Kms away from Varanasi city. |
| Hand Pump, Kotwa | 150 - 180 | This hand pump is near the Chauraha in Kotwa village which is about 12 Kms from Varanasi city. Only low income group people live here and cultivation is mostly practiced in the area. |
| Hand Pump, Kamaoli | 160 - 180 | This hand pump is near a Tea Stall in Kamaoli village. This village is also far from the city. No known water problem has been reported. |
| Tube well, Khajuri | 110 - 120 | This tube well is near the District Jail. This area is dominated by people of LIG and MIG. It is a residential area. No known water quality problem exists. |
| Tube well, Sigra | 500 - 600 | This tube well is near the building of Nagar Nigam, Sigra. It is in a locality where many Govt. Offices are also situated. The area is very busy. The water quality is satisfactory. |

| | | |
|---|---|---|
| Tube well, Lahartara | 430 - 450 | This tube well is near Prathmik Vidyalaya and Nagar Nigam. Lahartara has residential colony of railway employees and also important loco shed of railways. The water quality is reported to be satisfactory. |
| Tube well, Near Cantt. Railway Station | 250 - 300 | This tube well is located near the Cant. Railway Station and Roadways Bus Stand in Maldahiya. It is a residential area and also has commercial activities. No known problem of water quality exists. |
| ***Landfill Area*** | | |
| Tube well, Rajghat | 100 - 150 | This tube well is near the Chungi and close to the municipal solid waste disposal site. A few residential colonies are also present in the area. This tube well is also quite old |

- The industrial areas, residential areas, municipal solid waste disposal (land fill) area have also been identified and samples collected accordingly.
- There is no bulk storage depot of Petroleum products in Varanasi city.

Varanasi basically is a religious place which has historical and tourist importance. The city also enjoys the status of an important place in India in the production of various handicraft items like silk sarees, carpets, jari jamdani, rags, customary knitting of jamavars etc. The Banarasi sarees are famous for their uniqueness not only in India but abroad also. The real industrial development started taking place in the city after the year 1950. The city is congested and few industries are present in the city also. The new conforming industrial areas have been developed away from the city

Various sites are being used in the city for dumping of municipal solid waste. These sites include (1) Purana Pull (2) Palang Sahid (3) Kabir Math (4) Raj Ghat etc. The rest comes under residential area out of which many places are very congested. The intensity of sampling locations is more in residential areas because of the intensity of ground water pumping and close variations in ground water withdrawal from place to place. The quality of ground water is also widely variable in different areas which are in turn varying in quality of recharging source water.

## 2.27 Mumbai (Including Navi Mumbai & Thane)

Ground water forms the major source of water supply for all the basic need of humans. Therefore its proper utilization, conservation, and the reasons for pollution gain the prime importance. The TMC has taken the initiative in the assessment of ground water quality of Thane Municipal Corporation, area along with adjoining corporations Viz Mumbai Municipal Corporation (Mulund to Vikroli) and NaviMumbai Municipal Corporation (Digha to Rabale areas. This entire plan would help in stating the water quality and accordingly its use. And if necessary the further treatment of water as per the recommendation, its proper use and its conservation will be suggested. It has been decided that the sampling will be done during pre-monsoon, monsoon and post monsoon period.

# 3.0 EXPERIMENTAL METHODOLOGY

## 3.1 Sampling and Preservation

Twenty five ground water samples from each metropolitan city were collected each during pre- as well as post-monsoon seasons during the year 2004 -2006 from various abstraction sources at various depths covering extensively populated area, commercial, industrial, agricultural and residential colonies so as to obtain a good areal and vertical representation and preserved by adding an appropriate reagent (Jain and Bhatia, 1988; APHA, 1992). The hand pumps were continuously pumped prior to the sampling, to ensure that ground water to be sampled was representative of ground water aquifer. The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 mL/lit.) Samples for pesticides analysis were collected in glass bottles while samples for bacteriological analysis were collected in sterilized high density polypropylene bottles covered with aluminium foils. All the samples were stored in sampling kits maintained at $4^{o}C$ and brought to the laboratory for detailed chemical and bacteriological analysis.

## 3.2 Chemicals and Reagents

All general chemicals used in the study were of analytical reagent grade (Merck/BDH). Standard solutions of metal ions were procured from Merck, Germany. Pesticide and PAH standards were procured from Sigma-Aldrich, USA. Bacteriological reagents were obtained from HiMedia. De-ionized water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use. All glassware and reagents used for bacteriological analysis were thoroughly cleaned and sterilized before use. All glassware for pesticides and poly aromatic hydrocarbons analysis were rinsed with chromatography grade solvents prior to use.

## 3.3 Physico-chemical and Bacteriological Analysis

The physico-chemical and bacteriological analysis was performed following standard methods (Jain and Bhatia, 1988; APHA, 1992). The brief details of analytical methods and equipment used in the study are given in Table 3.1. Ionic balance was determined the error in the ionic balance for majority of the samples was within 5%.

**Table 3.1 Analytical methods and equipment used in the study**

| S.No. | Parameter | Method | Equipment |
|---|---|---|---|
| **A.** | **Physico-chemical** | | |
| 1. | pH | Electrometric | pH Meter |
| 2. | Conductivity | Electrometric | Conductivity Meter |
| 3. | TDS | Electrometric | Conductivity/TDS Meter |
| 4. | Alkalinity | Titration by $H_2SO_4$ | - |

| | | | |
|---|---|---|---|
| 5. | Hardness | Titration by EDTA | - |
| 6. | Chloride | Titration by $AgNO_3$ | - |
| 7. | Sulphate | Turbidimetric | Turbidity Meter |
| 8. | Nitrate | Ultraviolet screening | UV-VIS Spectrophotometer |
| 9. | Phosphate | Molybdophosphoric acid | UV-VIS Spectrophotometer |
| 10. | Fluoride | SPADNS | UV-VIS Spectrophotometer |
| 11. | Sodium | Flame emission | Flame Photometer |
| 12. | Potassium | Flame emission | Flame Photometer |
| 13. | Calcium | Titration by EDTA | - |
| 14. | Magnesium | Titration by EDTA | - |
| 15. | Boron | Carmine | UV-VIS Spectrophotometer |
| 16. | BOD | 5 days incubation at $20^{o}C$ followed by titration | BOD Incubator |
| 17. | COD | Digestion followed by titration | COD Digestor |
| **B** | **Bacteriological** | | |
| 18. | Total coliform | Membrane Filtration (MF) technique | Filtration Assembly, Bacteriological Incubator |
| 19. | Faecal coliform | | |
| **C.** | **Heavy Metals** | | |
| 20. | Iron | Digestion followed by Atomic Spectrometry | Atomic Absorption Spectrometer |
| 21. | Manganese | | |
| 22. | Copper | | |
| 23. | Chromium | | |
| 24. | Lead | | |
| 25. | Cadmium | | |
| 26. | Zinc | | |
| **D.** | **Pesticides and Polynuclear Aromatic Hydrocarbons** | | |
| 27. | Aldrin | Gas chromatography | Gas Chromatograph with ECD, NPD and FID |
| 28. | DDT | | |
| 29. | DDE | | |
| 30. | DDD | | |
| 31. | Methoxychlor | | |
| 32. | Endosulphan | | |
| 33. | Thionazin | | |
| 34. | Sulfotepp | | |
| 35. | Phorate | | |
| 36. | Dimethoate | | |
| 37. | Disulfoton | | |
| 38. | Methyl Parathion | | |
| 39. | Ethyl parathion | | |
| 40. | Famphur | | |
| 41. | Chlorpyriphos | | |
| 42. | Ethion | | |
| 43. | PAHs | | |

## 3.4 Metal Ion Analysis

Metal ion concentrations were determined by atomic absorption spectrometry using Perkin-Elmer Atomic Absorption Spectrometer (Model 3110) using air-acetylene flame. Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis. The detection limits for iron, manganese, copper, nickel, chromium, lead, cadmium and zinc are 0.003, 0.001, 0.001, 0.004, 0.002, 0.01, 0.0005 and 0.0008 mg/L respectively.

## 3.5 Pesticide and PAH Analysis

The water samples for pesticide and PAH analysis were extracted with n-hexane and dichloro methane separately and respectively three times and the combined extract was concentrated using Kuderna Danish assembly under reduced vacuum. The moisture from the extracts was removed by using anhydrous sodium sulphate. The analysis of the pesticides and PAH was carried using Aimil Nucon Gas Chromatograph with ECD, NPD and FID detectors. The column used was EQUITY-5, 30 m with internal diameter of 0.25mm. Nitrogen gas was used as carrier gas at 2.0 ml/min with 28 ml/min as the makeup gas. The temperatures of the oven, detector and injector were 280, 285 and 300$^{O}$C, respectively. The qualitative and quantitative determination of the pesticides and PAH were carried out by comparing the retention time and peak area of the pesticides/PAH. The confirmation of the pesticides/PAH in the water samples was achieved by using standard internal addition method.

# 4.0 GROUND WATER QUALITY

## 4.1 Drinking Water Specifications

The Bureau of Indian Standards (BIS) earlier known as Indian Standards Institution (ISI) has laid down the standard specifications for drinking water (BIS, 1991). In order to enable the users, exercise their discretion towards water quality criteria, the maximum permissible limit has been prescribed especially where no alternate source is available. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purpose (Table 4.1).

**Table 4.1 Drinking water specifications (IS:10500:1991)**

| S.No. | Characteristics | Desirable limit | Permissible limit |
|---|---|---|---|
| **Essential Characteristics** | | | |
| 1. | Colour, Hazen units, Max | 5 | 25 |
| 2. | Odour | Unobjectionable | - |
| 3. | Taste | Agreeable | - |
| 4. | Turbidity, NTU, Max | 5 | 10 |
| 5. | pH value | 6.5 to 8.5 | - |
| 6. | Total hardness, mg/L, Max | 300 | 600 |
| 7. | Iron, mg/L, Max | 0.3 | 1.0 |
| 8. | Chlorides, mg/L, Max | 250 | 1000 |
| 9. | Residual free chlorine, mg/L, Max | 0.2 | - |
| **Desirable Characteristics** | | | |
| 10. | Dissolved solids, mg/L, Max | 500 | 2000 |
| 11. | Calcium, mg/L, Max | 75 | 200 |
| 12. | Magnesium, mg/L, Max | 30 | 75 |
| 13. | Copper, mg/L, Max | 0.05 | 1.5 |
| 14. | Manganese, mg/L, Max | 0.1 | 0.3 |
| 15. | Sulphate, mg/L, Max | 200 | 400 |
| 16. | Nitrate, mg/L, Max | 45 | 100 |
| 17. | Fluoride, mg/L, Max | 1.0 | 1.5 |
| 18. | Phenolic compounds, mg/L, Max | 0.001 | 0.002 |
| 19. | Mercury, mg/L, Max | 0.001 | - |
| 20. | Cadmium, mg/L, Max | 0.01 | - |
| 21. | Selenium, mg/L, Max | 0.01 | - |
| 22. | Arsenic, mg/L, Max | 0.05 | - |
| 23. | Cyanide, mg/L, Max | 0.05 | - |
| 24. | Lead, mg/L, Max | 0.05 | - |
| 25. | Anionic detergents | 0.02 | 1.0 |
| 26. | Chromium as $Cr^{6+}$, mg/L, Max | 0.05 | - |
| 27. | PAH, mg/L, Max | - | - |

| | | | |
|---|---|---|---|
| 28. | Mineral oil, mg/L, Max | 0.01 | 0.03 |
| 29. | Pesticides, mg/L, Max | Absent | 0.001 |
| 30. | Alkalinity, mg/L, Max | 200 | 600 |
| 31. | Aluminium, mg/L, Max | 0.03 | 0.2 |
| 32. | Boron, mg/L, Max | 1 | 5 |

The coliform group of bacteria is the principal indicator of suitability of water for domestic, industrial or other uses. The density of coliform group is the criteria for the degree of contamination and has been the basis for bacteriological water quality standard. In ideal situation all the samples taken from the distribution system should be free from coliform organisms but in practice, it is not attainable always and therefore, following standard for water has been recommended (BIS, 1991):

- 95% of water samples should not contain any coliform organisms in 100 ml throughout the year.
- No water sample should contain E.Coli in 100 ml water.
- No water sample should contain more than 10 coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

However, from bacteriological considerations, the objectives should be to reduce the coliform count to less than 10 per 100 ml and more importantly the absence of faecal coliform should be ensured.

The presence of coliforms in water is an indicator of contamination by human or from animal excrement. The presence of faecal colifirms in ground water indicates a potential public health problem, because faecal matter is a source of pathogenic bacteria and viruses. The ground water contamination from faecal coliform bacteria is generally caused by percolation from contamination sources (domestic sewage and septic tank) into the aquifers and also because of poor sanitation. Shallow wells are particularly susceptible for such contamination. The indiscriminate land disposal of domestic waste on surface, improper disposal of solid waste, leaching of waste water from landfill areas, further aggravate the chances of bacterial contamination in ground water.

## 4.2 Irrigation Water Quality Criteria

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 4.2. The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to electrical conductivity, sodium content, Sodium Absorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are given in Table 4.3.

**Table 4.2 Safe limits of electrical conductivity for irrigation water**

| S.No. | Nature of soil | Crop growth | Upper permissible safe limit of EC, μS/cm |
|---|---|---|---|
| 1. | Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately well drained | Semi-tolerant | 1500 |
| | | Tolerant | 2000 |
| 2. | Having textured soils having clay contents of 20-30% soils that are well drained internally and have good surface drainage system | Semi-tolerant | 2000 |
| | | Tolerant | 4000 |
| 3. | Medium textured soils having clay 10-20% internally very well drained and having good surface drainage system | Semi-tolerant | 4000 |
| | | Tolerant | 6000 |
| 4. | Light textured soils having clay less than 10% soil that have excellent internally and surface drainage system | Semi-tolerant | 6000 |
| | | Tolerant | 8000 |

Source: CGWB and CPCB (2000).

**Table 4.3 Guidelines for evaluation of irrigation water quality**

| Water class | Na, % | EC, μS/cm | SAR | RSC, meq/l |
|---|---|---|---|---|
| Excellent | < 20 | < 250 | < 10 | < 1.25 |
| Good | 20-40 | 250-750 | 10-18 | 1.25-2.0 |
| Medium | 40-60 | 750-2250 | 18-26 | 2.0-2.5 |
| Bad | 60-80 | 2250-4000 | > 26 | 2.5-3.0 |
| Very bad | > 80 | > 4000 | > 26 | > 3.0 |

Source: CGWB and CPCB (2000).

# 4.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov's diagram, U.S. Salinity Laboratory classification and Gupta's classification have been used in the present study to classify the ground water. Piper trilinear (Piper, 1944), Chadha's diagrams (1999) and Durov's diagram are used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) and Gupta's classification (1979) is used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage characteristics, quantity of water used, climate and salt tolerance of crop.

## 4.3.1 Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.

The diagram combine three distinct fields by plotting two triangular fields at the lower left and lower right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular fields at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na+K) are plotted as a single point according to conventional trilinear coordinates. The three anion groups ($HCO_3$, $SO_4$, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a ground water. The central diamond-shaped field is used to show the overall chemical character of the ground water by a third single point plotting, which is at the intersection of rays projected from the plotting of cations and anions. The position of this plotting indicates the relative composition of a ground water in terms of cation-anion pairs that correspond to the four vertices of the field. The three areas of plotting show the essential chemical character of ground water according to the relative concentrations of its constituents.

## 4.3.2 Chadha's Diagram

The diagram is a somewhat modified version of the piper trilinear diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plottings from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

In contrast, in Chadha's diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1. Alkaline earth exceeds alkali metals.
2. Alkali metals exceed alkaline earth.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. Such water has temporary hardness. The position of data points in the diagram represent $Ca^{2+}$ -$Mg^{2+}$-$HCO_3^-$ type, $Ca^{2+}$ -$Mg^{2+}$- dominant $HCO_3^-$ type, or $HCO_3^-$ - dominant $Ca^{2+}$ -$Mg^{2+}$- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram represents $Ca^{2+}$ -$Mg^{2+}$-$Cl^-$ type, $Ca^{2+}$ -$Mg^{2+}$- dominant $Cl^-$ - type or $Cl^-$ - dominant $Ca^{2+}$ -$Mg^{2+}$- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent $Na^+$-$Cl^-$- type, $Na_2SO_4$- type, $Na^+$-dominant $Cl^-$-type, or $Cl^-$-dominant $Na^+$-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent $Na^+$- $HCO_3^-$ -type, $Na^+$-dominant $HCO_3^-$ -type, or $HCO_3^-$ -dominant $Na^+$-type waters.

The Chadha's diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

### 4.3.3 Durov's Diagram

The trilinear Durov diagram is based on the percentage of major ion milli equivalents. The cation and anion values are plotted on two separate triangular plots and the data points are projected onto a square grid at the base of each triangle. The Durov plot is an alternative to the Piper plot. Since the data points are projected along the base of the triangle, which lies perpendicular to the third axis in each triangle, information about the concentration of the vertex elements (third element) is lost in the square grid. Changing the orientation of the elements in both triangles may improve the ability to detect distinct groups.

### 4.3.4 U. S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). The diagram for use in studying the suitability of ground water for irrigation purposes is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in µS/cm (Table 4.4).

**Table 4.4 U.S. Salinity Laboratory classification**

| | |
|---|---|
| **Salinity** | |
| Low Salinity (C1) | Low salinity water (C1) can be used for irrigation with most crops on most soils. |
| Medium Salinity (C2) | Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control. |
| High Salinity (C3) | High salinity water (C3) can not be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good tolerance should be selected. |
| Very High Salinity (C4) | Very high salinity water (C4) is not suitable for irrigation water under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate and irrigation water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected. |
| **SAR** | |
| Low SAR (S1) | Low sodium water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. |
| Medium SAR (S2) | Medium sodium water will present an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. This water may be used on coarse-textural or organic soils with good permeability. |
| High SAR (S3) | High sodium water may produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions. |
| Very High SAR (S4) | Very high sodium water is generally unsatisfactory for irrigation purposes. |

## 4.3.5 Gupta's Classification

Gupta (1979a,b) suggested a new classification for evaluation of quality of irrigation waters in arid and semi-arid zones of India. The classification has been adopted by ICAR Centres of the Coordinated Project on Management of Salt Affected Soils and Use of Saline Water in Agriculture.

It can be stated with certainty that both RSC and SAR influence the physical properties of soil in integrated manner. Whereas in low salinity waters, the effect of RSC is more prominent, in high salinity waters, it is SAR. However, it will be desirable to determine RSBC in waters having EC less than 3 $dSm^{-1}$, RSC and SAR for waters having EC between 3 and 5 $dSm^{-1}$ and SCAR for waters having EC greater than 5 $dSm^{-1}$. RSC/RSBC and SAR/SCAR both should not be high. RSBC up to 10.0 $meqL^{-1}$ is permissible provided that SAR is less than 10 and SAR up to 20 and 30 is permissible provided that RSC is less than 5 and 10 $meqL^{-1}$, respectively., It seems to be difficult to suggest a single parameter for RSC/RSBC and SAR/SCAR which could be used for practical purposes with precision.

The occurrence of B, F and Li, in natural ground waters is generally in small concentrations and therefore these elements should not cause concern in general. The routine classification with respect to these toxic elements may be avoided. Moreover, management practices to be followed for control of excessive salinity/sodicity take care of these elements and therefore no special management is needed.

In the classification of irrigation waters, it is presumed that the water will be used under average conditions with respect to several factors which influence its quality in relation to its use. Whether the salts dissolved in irrigation water will accumulate in the soil in injurious amounts and affect plant growth depends on one or more of the several parameters. Large deviations from the average for one or more of the variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use, under average conditions, would be a water of doubtful quality. This relationship to average conditions has therefore, to be kept in connection with the use of any general method for the classification of irrigation waters (Table 4.5).

**Salinity (EC):** The classification of irrigation waters with respect to salinity hazard on the basis of EC is based primarily on the development of salinity in the soil to the extent that yields are affected adversely. On the basis of electrical conductivity the irrigation waters may be classified into six salinity classes:

**Table 4.5(a) Gupta's classification**

| S.No. | Water type | Description |
|---|---|---|
| 1. | C-0,<br>Non-saline water<br>(EC < 0.2 $dSm^{-1}$) | Non-saline waters may create a severe permeability problem in the soil because infiltration rate into the soil is adversely affected due to lack of salts in the water to such an extent that the crop is not adequately supplied with water, and yield is reduced. |
| 2. | C-1,<br>Normal water<br>(EC 0.2 - 1.5 $dSm^{-1}$) | Normal water can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Large areas of citrus trees, (very sensitive plant) have been irrigated for many years with waters having EC 1.5 $dSm^{-1}$. These waters do not have any leaching requirement. These waters are general1y relatively high in Ca and low in chlorides. There is seldom any problem of high SAR/SCAR or of RSC/RSBC and toxic elements for the waters falling under this group. |
| 3. | C-2,<br>Low salinity water<br>(EC 1.5 - 3.0 $dSm^{-1}$) | Low salinity water can be used if a moderate amount of leaching occurs under the current irrigation practices. Most of the crops except sensitive ones |

| | | |
|---|---|---|
| | | comprising some horticultural and leguminous plants can be grown on all soils except very heavy textured, with impeded drainage. These waters do not have any significant problem of SAR/SCAR and toxic elements but may have some problem due to RSC/RSBC. |
| 4. | C-3, Medium salinity water (EC 3.0 - 5.0 $dSm^{-1}$) | Medium salinity water can be used on soils provided with good drainage such that leaching fraction is not less than 0.3. Most of semi-tolerant and tolerant crops can be grown under good management. These waters may have a moderate problem of high SAR/SCAR and RSC/RSBC but seldom a significant problem of toxic elements. Interestingly, there is evidence to show that optimum yields of many tolerant crops are obtained under irrigation with waters belonging to this EC group. |
| 5. | C-4, High salinity water (EC 5.0 - 10.0 $dSm^{-1}$) | High salinity water is suitable for irrigation on soils provided with very good drainage so that leaching fraction is always greater than 0.3 and $EC_e$ does not exceed $EC_{iw}$. Only salt tolerant crops can be grown under good management. Higher the total and seasonal rainfall during the crop growth period, better the usability. These waters generally may have a significant problem of medium to high SAR/SCAR but no problem due to RSC/RSBC. However, high SAR (>30) values disqualify these waters for satisfactory use for prolonged periods. Summer fallowing is sometimes necessary for effecting desalinisation, and amendments may also have to be used to take care of hazards due to sodium and/or toxic elements. |
| 6. | C-5, Very high salinity waters (EC > 10 $dSm^{-1}$) | Very high salinity water is directly not suitable for irrigation but may be used in cycle or in conjunction with low salinity waters, for example, canal waters. |

**Sodicity (SAR/SCAR):** Among the soluble salts of irrigation water, sodium is considered to be the most hazardous. The water which might be considered as suitable according to salinity may not be suitable if sodium predominates. The classification of irrigation waters with respect to sodic hazard on the basis of SAR/SCAR is established primarily on the increase of exchangeable sodium and its effect on the physical condition of the soil. Since ESP of the soil is equa1 to SAR of the soil in equilibrium in turn with SAR of the water when $EC_{iw}$ and $EC_e$ are less than 5 $dSm^{-1}$. Mg to Ca ratio is less than one, SAR of the irrigation water directly reveals whether it is excessive for any crop and if it will deteriorate the physical properties of the soil. When $EC_{iw}$ is higher (5-10 $dSm^{-1}$) and Mg/Ca ratio is also higher (2-4), then SCAR will give better idea than SAR if ESP is to be depended on for soil appraisal and/or crop performance. On the basis of SAR/SCAR, the irrigation waters may be classified in six classes:

**Table 4.5(b) Gupta's classification**

| S.No. | Water type | Description |
|---|---|---|
| 1. | S-0, Non-sodic water (SAR/SCAR < 5) | Non-sodic water can be used for irrigation on almost all soils for all crops even those sensitive to sodium such as stone-fruit trees or wood trees. |
| 2. | S-1, Normal water (SAR/SCAR 5-10) | Normal waters can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium for growing all crops except some stone-fruit tree or wood trees which are specially sensitive to sodium. These waters do not have any requirement for leaching and/or amendments. |
| 3. | S-2, Low sodicity water (SAR/SCAR 10-20) | Low sodicity water can be used for crops which are semi-tolerant or tolerant to sodium on almost all soils so that LF is around 0.3. If soil contains gypsum or calcium carbonate, these waters can be used more successfully. EC should not be less than 1 to 2 $dSm^{-1}$ lest permeability problem develops. |
| 4. | S-3, Medium sodicity water (SAR/SCAR 20-30*)* | Medium sodicity water can be used only for crops which are tolerant to sodium on soils provided with good drainage such that LF is always greater than 0.3. If soils contain gypsum or calcium carbonate and if rainfall is appreciable and effective, these waters can be used very successfully. EC should not be less than 2 to 3 dSm-1 lest permeability problem develops. |
| 5. | S-4, High sodicity water (SAR/SCAR 30-40) | High sodicity water is not directly suitable for irrigation but may be used in cycle or in conjunction with low sodicity waters or with amendments such as gypsum. |
| 6. | S-5, Very high sodicity water (SAR/SCAR > 40) | Very high sodicity water is directly unsuitable for irrigation without drastic treatment. |

**Alkalinity (RSC/RSBC):** The classification of irrigation waters with respect to bicarbonate or carbonate alkalinity hazard on the basis of RSC or RSBC is based primarily on the precipitation of Ca or Mg and pairing of residual $CO_3$ or $HCO_3$ with sodium or formation of $Na_2CO_3$ in the soil and increasing SAR/ESP, characterizing it as alkali soil. Since appreciable amount of carbonates occurs only in such waters as have high pH (>8.5), RSC should be calculated for high pH waters and RSBC for low pH (>8.5) waters. These waters also cause a permeability problem in the soil. On the basis of RSC/RSBC, the irrigation water may be classified in six classes:

**Table 4.5(c) Gupta's classification**

| S.No. | Water type | Description |
|---|---|---|
| 1. | A-0, Non-alkaline water (RSC/RSBC –ve*)* | Non-alkaline water can be used on irrigation on almost all soils for all crops for indefinitely long periods without any problem. |
| 2. | A-1, | Normal water can be used for irrigation on almost all |

| | | |
|---|---|---|
| | Normal water (RSC/RSBC 0 $meqL^{-1}$) | soils for all crops even those very sensitive to carbonates or bicarbonates. These waters may not create any permeability problem. |
| 3. | A-2, Low-alkalinity water (RSC/RSBC tr. - 2.5 $meqL^{-1}$) | Low-alkalinity water can be used for irrigation on almost all soils for all crops. These waters may not create any permeability problem unless drainage is impeded, rainfall is unduly low and evaporation is very high. |
| 4. | A-3, Medium-alkalinity waters (RSC/RSBC 2.5 - 5.0 $meqL^{-1}$) | Medium-alkalinity water can be used for irrigation on almost all soils with little danger of the development of harmful levels of alkali for growing all crops except those which are specifically sensitive to carbonate or bicarbonates. Optimum yields of several alkali tolerant crops are obtained when RSBC is in this range. |
| 5. | A-4, High-alkalinity waters (RSC/RSBC 5.0-10.0 $meqL^{-1}$) | High-alkalinity water can be used for irrigation on soils provided with good drainage such that LF is not less than 0.3, for growing semi-tolerant and tolerant crops to sodium. EC should be <3.0 $dSm^{-1}$ and SAR < 10. Rainfall should be appreciable and effective (>400 mm) and evaporation must be low (< 2000 mm) for the prolonged successful utilisation of such waters. If SAR is > 10, use of gypsum may be required. |
| 6. | A-5, Very high alkalinity waters (RSC/RSBC > l0.0 $meqL^{-1}$) | Very high alkalinity water is directly not suitable for irrigation but may be used in cycle or in conjunction with low alkalinity waters or with the use of amendments such as gypsum. High alkalinity with preponderance of carbonates associated with high EC and SAR/SCAR prohibits the use of these waters for irrigation. |

# 5.0 RESULTS AND DISCUSSION

## 5.1 Faridabad

### 5.1.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Faridabad were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.1.1. The details of sampling locations and source and depth wise distribution are given in Table 5.1.1 and 5.1.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.1.3 and 5.1.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.1.5 to 5.1.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.1.2 to 5.1.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Faridabad are mostly confined within the range 6.13 to 7.61 during pre-monsoon season and 7.18 to 8.25 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 526 to 4970 μS/cm during pre-monsoon season and 464 to 4569 μS/cm during post-monsoon season with almost all the samples having conductivity value above 1000 μS/cm during both pre- and post-monsoon seasons. The maximum conductivity value of 4970 μS/cm was observed at Sector 23 during pre- and post-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 337 to 3181 mg/L during pre-monsoon season and 297 to 2924 mg/L during post-monsoon season indicating high mineralization in the area. About 80% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L while about 20% of the samples even exceed the maximum permissible limit of 2000 mg/L (Table 5.1.5). It may be concluded that there is more mineralization of ground water at depth upto 40 meters. The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 137 to 719 mg/L during pre-monsoon season and 121 to 616 mg/L during post-monsoon season. Three samples exceed the maximum permissible limit of 600 mg/L during pre-monsoon season . The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 151 to 1412 mg/L during pre-monsoon season and 138 to 1301 mg/L during post-monsoon season. About 16% of the samples of the metropolitan city of Faridabad fall within the desirable limit of 300 mg/L while 48% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 36% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.1.7). During the post-monsoon season 24% of the samples exceed the maximum permissible limit of 600 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 44 to 489 and 10 to 50 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 41 to 454 mg/L and 8.8 to 48 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.5(a&b) and 5.1.6(a&b) respectively.

The concentration of sodium in the study area varies from 29 to 492 mg/L during pre-monsoon season and 22 to 455 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Faridabad varies from 1.2 to 74 mg/L during pre-monsoon season and 0.8 to 51 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 44% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 35 to 881 mg/L during pre-monsoon season and 34 to 798 mg/L during post-monsoon season. More than 50% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.1.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 31 to 800 mg/L during pre-monsoon season and 27 to 745 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Faridabad, 64% of the samples analysed fall within the desirable limit of 200 mg/L while 24% of the samples exceed the desirable limit but are within the permissible limit of 400 mg/L and 12% of the samples even exceed the maximum permissible limit of 400 mg/L during pre-monsoon season (Table 5.1.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Faridabad varies from 0.9 to 28 mg/L during pre-monsoon season and 0.5 to 23 mg/L during post-monsoon season indicating that all the samples of the study area falls within the desirable limit of 45mg/L in both pre- and post-monsoon season (Table 5.1.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Faridabad is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.14 to 4.70 mg/L during pre-monsoon season and 0.04 to 3.90 mg/L during post-monsoon season. About 60% samples of the metropolitan city falls within the desirable limit 0f 1.0 mg/L during pre- as well as post-monsoon season (Table 5.1.13). At few locations the concentration of fluoride even exceeds the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in almost all the samples. The alkalinity values also exceed the desirable limit in more than 90% of the samples in both the seasons. From the hardness point of view, 16% of the samples are within desirable limit during pre-monsoon season, 48% samples exceed the desirable limit but are within permissible limit and 36% samples even exceeds the maximum permissible limit. The chloride, sulphate and fluoride contents are within the desirable limits in about 60% of the samples. The concentration of nitrate is well within the desirable limit in all the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Faridabad do not show any bacterial contamination in any of the ground water sample during both pre- and post-monsoon seasons.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre-and post-monsoon seasons from the metropolitan city of Faridabad are given in Tables 5.1.15 and 5.1.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.1.17 to 5.1.24 and graphically shown in Fig. 5.1.11 to 5.1.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Faridabad ranges from 169 to 3860 µg/L during pre-monsoon season (Table 5.1.15) and 563 to 7070 µg/L during post-monsoon season (Table 5.1.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.1.11. The Bureau of Indian Standards has recommended 300 µg/L as the desirable limit and 1000 µg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 937 µg/L during pre-monsoon season (Table 5.1.15) and 490 µg/L during post-monsoon season (Table 5.1.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.1.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that about 60% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L. About 24% of the samples even exceed the maximum permissible limit of 300 µg/L during pre-monsoon season (Table 5.1.18). High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata.

Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 255 μg/L during pre-monsoon season (Table 5.1.15) and 140 μg/L during post-monsoon season (Table 5.1.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.1.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Faridabad, more than 90% of the samples fall below the desirable limit of 50 μg/L and remaining about 10% samples exceeds the desirable limit but are within the maximum permissible limit (Table 5.1.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 198 μg/L during pre-monsoon season (Table 5.1.15) and 28 μg/L during post-monsoon season (Table 5.1.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.1.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Faridabad, almost all the samples fall well within the desirable limit for drinking water.

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 132 µg/L during pre-monsoon season (Table 5.1.15) and 104 µg/L during post-monsoon season (Table 5.1.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.1.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Faridabad, 48% of the samples fall within the permissible limit during pre-monsoon season and 72% of the samples falls within permissible limit during the post-monsoon season. Remaining 52% and 28% of the samples crosses the permissible limit during pre- and post-monsoon seasons respectively and not safe for drinking water (Table 5.1.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 14 µg/L during pre-monsoon season (Table 5.1.15) and 2 to 16 µg/L during post-monsoon season (Table 5.1.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.1.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Faridabad, about 70% of the samples are found within the permissible limit during pre- as well as post-monsoon season (Table 5.1.23). The drinking water having more than 10 µg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 16 to 10250 µg/L during pre-monsoon season (Table 5.1.15) and 167 to 4080 µg/L during post-monsoon season (Table 5.1.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.1.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Faridabad, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron

(28% samples), manganese (24% samples), nickel (76% samples), chromium (4%), lead (52% samples) and cadmium (24% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Faridabad, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.1.25 and 5.1.26. Out of the seven chlorinated pesticides analysed, only four pesticides (Aldrin, DDT, Endosulphan and Methoxychlor) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city only one PAH (acenaphthylene = 1.50 μg/L) was detected at site No. 8.

# 5.1.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity

- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Faridabad are given in Table 5.1.27.

# Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Faridabad varies widely from 526 to 4970 μS/cm during pre-monsoon season and 464 to 4569 μS/cm during post-monsoon season and as such the water is normally not safe for deep black, alluvial and textured soils. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 1.03 to 9.51 during pre-monsoon season and 0.81 to 8.97 during post-monsoon season. The sodium percentage in the study area was found to vary from 21.3 to 70.4% during pre-monsoon season and 22.2 to 71.7 during post-monsoon season. About 15% of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is susceptible to residual sodium carbonate hazard at many locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

# 5.1.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and

Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.1.28 and 5.1.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Faridabad have been plotted on trilinear diagram for both the surveys (Fig. 5.1.19 and 5.1.20) and results have been summarized in Table 5.1.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to Na-K-Cl-$SO_4$ hydrochemical facies.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Faridabad have been plotted on Chadha' diagram (Fig. 5.1.21 and 5.1.22) and results have been summarized in Table 5.1.28. It is evident from the results that majority of the samples of the metropolitan city belong to Group 6 (Ca-Mg-Cl-$SO_4$) or Group 5 (Ca-Mg-$HCO_3$) hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to Group 7 (Na-K-Cl-$SO_4$) hydrochemical facies.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.1.23 and 5.1.24 respectively. . It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to Na-K-Cl-$SO_4$ hydrochemical facies.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Faridabad has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.1.25 and 5.1.26) and the results have been summarized in Table 5.1.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Faridabad falls under water types C3-S1 followed by C4-S2, C4-S3 and C4-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. C4-S1 type water (very high salinity and low SAR) cannot be used on any type of soils.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Faridabad has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.1.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to medium saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.2 Delhi

## 5.2.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Delhi were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.2.1. The details of sampling locations and source and depth wise distribution are given in Table 5.2.1 and 5.2.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.2.3 and 5.2.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.2.5 to 5.2.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.2.2 to 5.2.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Delhi are mostly confined within the range 6.1 to 7.81 during pre-monsoon season and 7.0 to 7.8 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 507 to 12180 μS/cm during pre-monsoon season and 448 to 2804 μS/cm during post-monsoon season with almost all the samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 12180 μS/cm was observed at Parhaladpur during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 324 to 7795 mg/L during pre-monsoon season and 287 to 1795 mg/L during post-monsoon season indicating high mineralization in the area. More than 70% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon season and only two samples exceeds the maximum permissible limit of 2000 mg/LOOKED during pre-monsoon season (Table 5.2.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 198 to 834 mg/L during pre-monsoon season and 179 to 738 mg/L during post-monsoon season. More than 90% of the samples exceed the desirable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 61 to 4388 mg/L during pre-monsoon season and 40 to 1004 mg/L during post-monsoon season. About 40% of the samples of the metropolitan city of Delhi fall within the desirable limit of 300 mg/L while 50% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 8% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.2.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 19 to 810 and 3.2 to 575 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 13 to 310 mg/L and 3 to 56 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.5(a&b) and 5.2.6(a&b) respectively.

The concentration of sodium in the study area varies from 16 to 1058 mg/L during pre-monsoon season and 11 to 350 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Delhi varies from 0.4 to 36 mg/L during pre-monsoon season and 0.8 to 25 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian

Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 16% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 12 to 4775 mg/L during pre-monsoon season and 10 to 714 mg/L during post-monsoon season. More than 60% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.2.10). Only one sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 5 to 513 mg/L during pre-monsoon season and 3 to 430 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Delhi, 88% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.2.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Delhi varies from 0.1 to 153 mg/L during pre-monsoon season and 0.1 to 105 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 80% of the samples fall within the desirable limit of 45 mg/L while only 1 sample exceed the maximum permissible limit of 100 mg/L (Table 5.2.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.9(a&b). CGWB (2000) has reported maximum value of 1600 mg/L at Saboli in Shahdara block (CGWB, 2000).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Delhi is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.09 to -8.50 mg/L during pre-monsoon season and 0.01 to 4.60 mg/L during post-monsoon season. About 20% of the samples of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.10(a&b). Similar findings were also reported by CGWB (2000). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of total dissolved solids and hardness values exceeds the maximum permissible limit in about 8% of the samples, chroride, sulphate and nitrate concentrations exceed the maximum permissible limit in 4% of the samples while fluoride content exceeds the maximum permissible limit in 20% of the samples. The alkalinity values falls within the desiravble limits for all the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Delhi indicates bacterial contamination at few locations (Table 5.2.14). Five samples even exceed the permissible limit for drinking water and are not suitable for drinking water.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Delhi are given in Tables 5.2.15 and 5.2.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.2.17 to 5.2.24 and graphically shown in Fig. 5.2.11 to 5.2.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Delhi ranges from 113 to 23625 µg/L during pre-monsoon season (Table 5.2.15) and 157 to 14400 µg/L during post-monsoon season (Table 5.2.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.2.11. The Bureau of Indian Standards has recommended 300 µg/L as the desirable limit and 1000 µg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 970 during pre-monsoon season (Table 5.2.15) and 2465 µg/L during post-monsoon season (Table 5.2.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.2.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 72% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 16% of the samples even exceed the maximum permissible limit of 300 µg/L during both pre- and post-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 34 µg/L during pre-monsoon season (Table 5.2.15) and 21 µg/L during post-monsoon season (Table 5.2.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.2.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Delhi, all the samples falls within the desirable limit during both pre- and post-monsoon seasons (Table 5.2.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 36 µg/L during pre-monsoon season (Table 5.2.15) and 15 µg/L during post-monsoon season (Table 5.2.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.2.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Delhi, almost all the samples fall well within the desirable limit for drinking water (Table 5.2.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 233 µg/L during pre-monsoon season (Table 5.2.15) and 58 µg/L during post-monsoon season (Table 5.2.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.2.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Delhi, 88% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining 12% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.2.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 30 μg/L during pre-monsoon season (Table 5.2.15) and 6 to 16 μg/L during post-monsoon season (Table 5.2.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.2.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Delhi, 96% of the samples are found within the permissible limit during pre-monsoon season (Table 5.2.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 28 to 890 μg/L during pre-monsoon season (Table 5.2.15) and 28 to 9856 μg/L during post-monsoon season (Table 5.2.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.2.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Delhi, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (12% samples), manganese (16% samples), nickel (60% samples), lead (12% samples) and cadmium (4% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Delhi, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.2.25 and 5.2.26 Out of the seven chlorinated pesticides analysed, two pesticides (Aldrin, DDT) have been detected at few locations in the ground water of the metropolitan city. However, the values of these pesticides were within the permissible limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Delhi.

## 5.2.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Delhi are given in Table 5.2.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Delhi vary widely from 507 to 12180 µS/cm during pre-monsoon season and 448 to 2804 µS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from

0.49 to 8.67 during pre-monsoon season and 0.37 to 8.06 during post-monsoon season. The sodium percentage in the study area was found to vary from 14.9 to 77.6 % during pre-monsoon season and -13.1 to 81.7 during post-monsoon season. About 16% of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

# 5.2.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha’s diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta’s classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.2.28 and 5.2.29.

# Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Delhi have been plotted on trilinear diagram for both the surveys (Fig. 5.2.19 and 5.2.20) and results have been summarized in Table 5.2.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-$HCO_3$ type followed by Na-K-Cl-$SO_4$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Delhi have been plotted on Chadha' diagram (Fig. 5.2.21 and 5.2.22) and results have been summarized in Table 5.2.28. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-$HCO_3$ type followed by Na-K-Cl-$SO_4$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.2.23 and 5.2.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-$HCO_3$ type followed by Na-K-Cl-$SO_4$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Delhi has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.2.25 and 5.2.26) and the results have been summarized in Table 5.2.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Delhi falls under water types C3-S1 followed by C1-S1. Few samples also belong to C4-S1, C4-S2, C4-S3 and C4-S4 type. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. C4-S1, C4-S2, C4-S3 and C4-S4 type water cannot be used on any type of soils.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Faridabad has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.2.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low salinity water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to medium alkalinity water as per alkalinity classification.

## 5.3 Jaipur

## 5.3.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Jaipur were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.3.1. The details of sampling locations and source and depth wise distribution are given in Table 5.3.1 and 5.3.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.3.3 and 5.3.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.3.5 to 5.3.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.3.2 to 5.3.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Jaipur are mostly confined within the range 5.7 to 8.0 during pre-monsoon season and 6.9 to 8.0 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 486 to 2300 μS/cm during pre-monsoon season and 430 to 2110 μS/cm during post-monsoon season with about 50% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2300 μS/cm was observed at Ganesh Colony during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 311 to 1472 mg/L during pre-monsoon season and 275 to 1350 mg/L during post-monsoon season indicating high mineralization in the area. More than 50% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon season. No sample exceeds the maximum permissible limit of 2000 mg/L during during both pre- and post-monsoon seasons (Table 5.3.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 235 to 618 mg/L during pre-monsoon season and 208 to 590 mg/L during post-monsoon season. About 36% of the samples exceed the desirable limit of 200 mg/L during pre-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 105 to 890 mg/L during pre-monsoon season and 103 to 783 mg/L during post-monsoon season. About 48% of the samples of the metropolitan city of Jaipur fall within the desirable limit of 300 mg/L while 28% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 24% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.3.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 21 to 222 and 2.9 to 133 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 19 to 222 mg/L and 8 to 117 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.5(a&b) and 5.3.6(a&b) respectively.

The concentration of sodium in the study area varies from 19 to 222 mg/L during pre-monsoon season and 17 to 160 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Jaipur varies from 0.6 to 22 mg/L during pre-monsoon season and 0.2 to 29 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, only few samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 4.6 to 432 mg/L during pre-monsoon season and 3 to 362 mg/L during post-monsoon season. More than 80% of the samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.3.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 1 to 155 mg/L during pre-monsoon season and 1 to 125 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Jaipur, all the samples analysed fall within the desirable limit of 200 mg/L (Table 5.2.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Jaipur varies from 7.9 to 375 mg/L during pre-monsoon season and 8.8 to 318 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 40% of the samples fall within the desirable limit of 45 mg/L while about 40% sample exceed the maximum permissible limit of 100 mg/L (Table 5.3.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Jaipur is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.45 to 3.20 mg/L during pre-monsoon season and 0.10 to 2.80 mg/L during post-monsoon season. About 40% of the samples of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during pre-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that no sample of the study area exceeds the maximum permissible limit for TDS and alkalinity. From the hardness point of view about 20% samples exceed the maximum permissible limit. Chloride and sulphate are within the desirable limit for most of the samples. About 40% samples exceed the maximum permissible limit for nitrate and fluoride during pre-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Jaipur indicates bacterial contamination at few locations (Table 5.3.14). However, no sample exceed the permissible limit of 10 coliform per 100 ml of sample.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Jaipur are given in Tables 5.3.15 and 5.3.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.3.17 to 5.3.24 and graphically shown in Fig. 5.3.11 to 5.3.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Jaipur ranges from 40 to5293 μg/L during pre-monsoon season (Table 5.3.15) and 81 to 11024 μg/L during post-monsoon season (Table 5.3.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.3.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 325 during pre-monsoon season (Table 5.315) and 189 μg/L during post-monsoon season (Table 5.316). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.312. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that more than 90% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L while one sample even exceed the maximum permissible limit of 300 μg/L during pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 57 μg/L during pre-monsoon season (Table 5.315) and 924 μg/L during post-monsoon season (Table 5.316). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.313. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Jaipur, 96% samples falls within the desirable limit during both pre- and post-monsoon seasons (Table 5.3.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 18 μg/L during pre-monsoon season (Table 5.3.15) and 16 μg/L during post-monsoon season (Table 5.3.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.3.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jaipur, all the samples fall well within the permissible limit for drinking water (Table 5.3.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, $Cr(3+)$, being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 51 μg/L during pre-monsoon season (Table 5.3.15) and 155 μg/L during post-monsoon season (Table 5.3.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.3.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Jaipur, more than 80% of the samples fall within the permissible limit during pre- and post-monsoon seasons (Table 5.3.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 13 μg/L during pre-monsoon season (Table 5.3.15) and 3.8 to 12 μg/L during post-monsoon season (Table 5.3.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.3.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Jaipur, 88% of the samples are found within the permissible limit during pre-monsoon season (Table 5.3.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 29 to 2600 μg/L during pre-monsoon season (Table 5.315) and 35 to 3020 μg/L during post-monsoon season (Table 5.316). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.318. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jaipur, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (44% samples), manganese (4% samples), nickel (32% samples), lead (8% samples) and cadmium (12% samples) during pre-monsoon season. Almost similar trend was observed during post-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Jaipur , all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.3.25 and 5.3.26 Out of the seven chlorinated pesticides analysed, four pesticides (Aldrin, DDT, Endosulphan and Methoxychlor) have been detected at few locations in the ground water of the metropolitan city. However, the concentrations of these pesticides were within the prescribed limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Jaipur.

## 5.3.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Jaipur are given in Table 5.3.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Jaipur vary widely from 486 to 2300 μS/cm during pre-monsoon season and 430 to 2110 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.44 to 4.09 during pre-monsoon season and 0.42 to 3.17 during post-monsoon season. The sodium percentage in the study area was found to vary from 10.6 to 59.4% during pre-monsoon season and 11.2 to 56.3 during post-monsoon season. No samples of the metropolitan city exceed the recommended value of 60% during both pre- and post-monsoon seasons.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.3.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.3.28 and 5.3.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Jaipur have been plotted on trilinear diagram for both the surveys (Fig. 5.3.19 and 5.3.20) and results have been summarized in Table 5.3.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Jaipur have been plotted on Chadha' diagram (Fig. 5.3.21 and 5.3.22) and results have been summarized in Table 5.2.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.3.23 and 5.3.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$ hydrochemical facies in both the seasons.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Jaipur has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.3.25 and 5.3.26) and the results have been summarized in Table 5.2.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Jaipur falls under water types C3-S1 followed by C1-S1. Two samples of the metropolitan city also belong to water type C4-S2.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Jaipur has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.3.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and low alkalinity to medium alkalinity water as per alkalinity classification**.**

# 5.4 Bhopal

## 5.4.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Bhopal were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.4.1. The details of sampling locations and source and depth wise distribution are given in Table 5.4.1 and 5.4.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.4.3 and 5.4.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.4.5 to 5.4.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.4.2 to 5.4.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Bhopal are mostly confined within the range 6.1 to 7.9 during pre-monsoon season and 5.2 to 7.9 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 175 to 1741 μS/cm during pre-monsoon season and 160 to 1498 μS/cm during post-monsoon season with about 40% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 1741 μS/cm was observed at Sawan Nagar Colony during pre-monsoon season. Almost similar findings were reported by CGWB (1999).

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 112 to 1114 mg/L during pre-monsoon season and 102 to 959 mg/L during post-monsoon season indicating low mineralization in the area. More than 75% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during pre-monsoon season. No sample exceeds the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.4.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 42 to 502 mg/L during pre-monsoon season and 46 to 458 mg/L during post-monsoon season. More than 75% of the samples exceed the desirable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 37 to 635 mg/L during pre-monsoon season and 35 to 557 mg/L during post-monsoon season. About 50% of the samples of the metropolitan city of Bhopal fall within the desirable limit of 300 mg/L while about 50% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and one sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.4.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 10 to 240 and 2.5 to 47 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 8.8 to 210 mg/L and 2.8 to 41 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.5(a&b) and 5.4.6(a&b) respectively.

The concentration of sodium in the study area varies from 7.0 to 132 mg/L during pre-monsoon season and 4.0 to 123 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Bhopal varies from 0.1 to 26 mg/L during pre-monsoon season and 0.1 to 21 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 8% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 8.2 to 240 mg/L during pre-monsoon season and 8.0 to 223 mg/L during post-monsoon season. All the samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.4.10). The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 5.5 to 141 mg/L during pre-monsoon season and 9 to 125 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Bhopal, all the samples analysed fall within the desirable limit of 200 mg/L (Table 5.4.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Bhopal varies from 0.9 to 145 mg/L during pre-monsoon season and 0.1 to 111 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 60% of the samples fall within the desirable limit of 45 mg/L while 28% samples exceed the desirable limit but are within the maximum permissible limit and 12% samples even exceed the maximum permissible limit of 100 mg/L (Table 5.4.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.9(a&b). CGWB also reported a high value of 215 mg/L at Bhanpura (CGWB, 1999).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Bhopal is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to -0.78 mg/L during pre-monsoon season and 0.02 to 1.22 mg/L during post-monsoon season. Almost all the samples of the metropolitan city fall within the desirable limit during pre-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man’s activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of most of the parameters are below the maximum permissible limits for TDS, alkalinity, magnesium, chloride, sulphate and fluoride. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Bhopal indicates bacterial contamination at many places (Table 5.4.14). Ten samples even exceed the permissible limit of 10 coliforms per 100 ml of sample during pre-monsoon season and are not suitable for drinking purpose.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Bhopal are given in Tables 5.4.15 and 5.4.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.4.17 to 5.4.24 and graphically shown in Fig. 5.4.11 to 5.4.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Bhopal ranges from 47 to 4265 μg/L during pre-monsoon season (Table 5.4.15) and 120 to 9792 μg/L during post-monsoon season (Table 5.4.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.4.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. High concentration of iron was also reported by CGWB (1999). Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 59 during pre-monsoon season (Table 5.4.15) and 115 μg/L during post-monsoon season (Table 5.4.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.4.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that almost all the samples of the metropolitan city fall within the desirable limit of 100 μg/L during both pre- and ppost-monsoon seasons. High concentration of manganese at one locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 15 μg/L during pre-monsoon season (Table 5.4.15) and 102 μg/L during post-monsoon season (Table 5.4.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.4.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Bhopal, all the samples fall within the desirable limit during pre-monsoon season (Table 5.4.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 11 μg/L during both pre- and post-monsoon seasons (Table 5.4.15 and 5.4.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.4.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Bhopal, all the samples fall well within the desirable limit for drinking water (Table 5.4.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 57 μg/L during pre-monsoon season (Table 5.4.15) and 49μg/L during post-monsoon season (Table 5.4.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.4.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Bhopal, 92% of the samples fall within the permissible limit and remaining 8% of the samples exceed the permissible limit in pre-monsoon season. The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 2 to 8 μg/L during pre-monsoon season (Table 5.4.15) and 2.6 to 11 μg/L during post-monsoon season (Table 5.4.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.4.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Bhopal, all the samples of the metropolitan city are found within the permissible limit during both pre- and post-monsoon seasons (Table

5.4.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 12 to 10690 μg/L during pre-monsoon season (Table 5.4.15) and 25 to 10270 μg/L during post-monsoon season (Table 5.4.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.4.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Bhopal, no sample exceed the maximum permissible limit of 15000 μg/L prescribed for drinking water.

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (16% samples), nickel (64% samples) and lead (8% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Bhopal, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.4.25and 5.3.26 Out of the seven chlorinated pesticides analysed, three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentration of these pesticides were within the permissible limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations only one PAH (benzo(k)fluoranthene = 0.23 μg/L) has been detected at site No. 9 of the metropolitan city of Bhopal.

## 5.4.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Bhopal are given in Table 5.4.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Bhopal vary from 175 to 1741 μS/cm during pre-monsoon season and 160 to 1498 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.49 to 3.44 during pre-monsoon season and 0.17 to 3.83 during post-monsoon season. The sodium percentage in the study area was found to vary from 11.6 to 84.7% during pre-monsoon season and -8.3 to 88.0 during post-monsoon season. Only one sample of the matropolitan city exceed the recommended value of 60% during both pre- and post-monsoon seasons and is not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to

deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.4.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.4.28 and 5.4.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Bhopal have been plotted on trilinear diagram for both the surveys (Fig. 5.4.19 and 5.4.20) and results have been summarized in Table 5.4.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Bhopal have been plotted on Chadha' diagram (Fig. 5.4.21 and 5.4.22) and results have been summarized in Table 5.4.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig.

5.4.23 and 5.4.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Bhopal has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.4.25 and 5.4.26) and the results have been summarized in Table 5.4.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Bhopal falls under water types C3-S1 followed by C2-S1 type.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Bhopal has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.4.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.5 Indore

## 5.5.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Indore were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.5.1. The details of sampling locations and source and depth wise distribution are given in Table 5.5.1 and 5.5.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.5.3 and 5.5.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.5.5 to 5.5.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.5.2 to 5.5.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Indore are mostly confined within the range 6.9 to 7.8 during pre-monsoon season and 6.7 to 7.9 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 696 to 2740 μS/cm during pre-monsoon season and 646 to 2430 μS/cm during post-monsoon season with about 90% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2740 μS/cm was observed at Chitawad during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 445 to 1754 mg/L during pre-monsoon season and 413 to 1555 mg/L during post-monsoon season indicating high mineralization in the area. More than 80% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.5.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 307 to 650 mg/L during pre-monsoon season and 282 to 617 mg/L during post-monsoon season. Almost all the samples exceed the desirable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 129 to 1046 mg/L during pre-monsoon season and 115 to 928 mg/L during post-monsoon season. About 40% of the samples of the metropolitan city of Indore fall within the desirable limit of 300 mg/L while 40% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 20% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.5.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 41 to 362 and 6.4 to 48 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 37 to 321 mg/L and 6 to 44 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons.

The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.5(a&b) and 5.5.6(a&b) respectively.

The concentration of sodium in the study area varies from 21 to 216 mg/L during pre-monsoon season and 19 to 187 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Indore varies from 0.3 to 3.6 mg/L during pre-monsoon season and 0.2 to 9.1 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, no sample exceed the guideline level of 10 mg/L during both pre- and post-monsoon seasons.

The concentration of chloride varies from 32 to 467 mg/L during pre-monsoon season and 27 to 432 mg/L during post-monsoon season. More than 80% of the samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon seasons (Table 5.5.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon seasons. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 17 to 155 mg/L during pre-monsoon season and 13 to 178 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Indore, all the samples analysed fall within the desirable limit of 200 mg/L (Table 5.5.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Indore varies from 0.1 to 212 mg/L during pre-monsoon season and 0.1 to 153 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 60% of the samples fall within the desirable limit of 45 mg/L while only 20% sample exceed the maximum permissible limit of 100 mg/L (Table 5.5.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Indore is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.40 mg/L during pre-monsoon season and 0.01 to 2.00 mg/L during post-monsoon season. About 96% of the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L and only one sample exceed the maximum permissible limit of 1.5 mg/L during post-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that no sample of the metropolitan city exceeds the maximum permissible limit for TDS, alkalinity, chloride and sulphate. From the hardness point of view 20% of the samples exceed the maximum permissible limit during pre-monsoon season. About 20% samples also exceed the maximum permissible limit for nitrate. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Indore indicates bacterial contamination at few locations (Table 5.5.14). One sample even exceed the permissible limit of 10 coliform per 100 ml of sample. However, no sample indicates any sign of faecal contamination.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Indore are given in Tables 5.5.15 and 5.5.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.5.17 to 5.2.24 and graphically shown in Fig. 5.5.11 to 5.5.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Indore ranges from 11 to 3946 μg/L during pre-monsoon season (Table 5.5.15) and 172 to 3099 μg/L during post-monsoon season (Table 5.5.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.5.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 164 during pre-monsoon season (Table 5.5.15) and 134 μg/L during post-monsoon season (Table 5.5.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.5.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 96% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L while remaining 4% although exceed the desirable limit but are within the maximum permissible limit of 300 μg/L during pre-monsoon season. No sample exceeds the maximum permissible limit of 300 μg/L during both pre- and post-monsoon seasons. High concentration of manganese at one location may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 63 μg/L during pre-monsoon season (Table 5.5.15) and 44 μg/L during post-monsoon season (Table 5.5.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.5.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Indore, almost all the samples fall within the desirable limit during both pre- and post-monsoon seasons (Table 5.5.19). As such the ground water of the metropolitan city (except one or two locations) can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 10 μg/L during pre-monsoon season (Table 5.5.15) and 12 μg/L during post-monsoon season (Table 5.5.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.5.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Indore, all the samples fall well within the permissible limit for drinking water (Table 5.5.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 51 μg/L during pre-monsoon season (Table 5.5.15) and 64 μg/L during post-monsoon season (Table 5.5.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.5.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Indore, about 90% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining about 10% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.5.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 1 to 11 μg/L during pre-monsoon season (Table 5.5.15) and 4.6 to 12 μg/L during post-monsoon season (Table 5.5.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.5.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Indore, more than 90% of the samples are found within the permissible limit during both pre- and post-monsoon seasons (Table 5.5.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 3 to 1500 μg/L during pre-monsoon season (Table 5.5.15) and 19 to 5010 μg/L during post-monsoon season (Table 5.5.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.5.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Indore, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (16% samples), nickel (84% samples), lead (4% samples) and cadmium (4% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Indore, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.5.25 and 5.5.26 Out of the seven chlorinated pesticides analysed, two pesticides (Aldrin, and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentration of these pesticides were within the permissible limits except for aldrine at site no. 15. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Indore.

## 5.5.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Indore are given in Table 5.5.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Indore vary widely from 696 to 2740 μS/cm during pre-monsoon season and 646 to 2430 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.46 to 4.45 during pre-monsoon season and 0.44 to 4.08 during post-monsoon season. The sodium percentage in the study area was found to vary from 10.3 to 56.6% during pre-monsoon season and 13.0 to 57.9 during post-monsoon season. No sample of the metropolitan city exceeds the recommended value of 60% during both pre- and post-monsoon seasons and the ground water is suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.5.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.5.28 and 5.5.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Indore have been plotted on trilinear diagram for both the surveys (Fig. 5.5.19 and 5.5.20) and results have been summarized in Table 5.5.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Na-K-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Indore have been plotted on Chadha' diagram (Fig. 5.5.21 and 5.5.22) and results have been summarized in Table 5.5.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Na-K-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.5.23 and 5.5.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Na-K-$HCO_3$. Few samples also belong to Ca-Mg-Cl-$SO_4$ and Na-K-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Indore has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.5.25 and 5.5.26) and the results have been summarized in Table 5.5.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Indore falls under water types C3-S1 followed by C2-S1 and C4-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Indore has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.5.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low salinity water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.6 Jabalpur

## 5.6.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Jabalpur were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.6.1. The details of sampling locations and source and depth wise distribution are given in Table 5.6.1 and 5.6.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.6.3 and 5.6.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.6.5 to 5.6.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.6.2 to 5.6.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Jabalpur are mostly confined within the range 7.15 to 8.15 during pre-monsoon season and 6.45 to 7.59 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 258 to 1731 μS/cm during pre-monsoon season and 226 to 1498 μS/cm during post-monsoon season with about 32% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 1731 μS/cm was observed at Ranipur during pre-monsoon season. Almost similar findings were reported by CGWB (2001).

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 165 to 1108 mg/L during pre-monsoon season and 145 to 959 mg/L during post-monsoon season indicating high mineralization in the area. More than 52% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre-monsoon seasons (Table 5.6.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 72 to 422 mg/L during pre-monsoon season and 61 to 403 mg/L during post-monsoon season. More than 80% of the samples exceed the desirable limit of 200 mg/L during pre-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 62 to 516 mg/L during pre-monsoon season and 53 to 458 mg/L during post-monsoon season. About 72% of the samples of the metropolitan city of Jabalpur fall within the desirable limit of 300 mg/L while 28% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L during pre-monsoon season (Table 5.6.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 17 to 187 and 0.6 to 41 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 15 to 167 mg/L and 0.7 to 41 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.5(a&b) and 5.6.6(a&b) respectively.

The concentration of sodium in the study area varies from 19 to 151 mg/L during pre-monsoon season and 14 to 127 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of

Jabalpur varies from 1.3 to 36 mg/L during pre-monsoon season and 0.1 to 11mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 16% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 5.2 to 188 mg/L during pre-monsoon season and 3.3 to 162 mg/L during post-monsoon season. All the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.6.10). The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 4.5 to 100 mg/L during pre-monsoon season and 5.1 to 97 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Jabalpur, all the samples analysed fall within the desirable limit of 200 mg/L (Table 5.6.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Jabalpur varies from 0.4 to 91mg/L during pre-monsoon season and 0.1 to 61mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 92% of the samples fall within the desirable limit of 45 mg/L while only 8 sample exceed the desirable limit but are within the maximum permissible limit of 100 mg/L (Table 5.6.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Jabalpur is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to -1.63 mg/L during pre-monsoon season and 0.02 to 1.40 mg/L during post-monsoon season. About 12% of the samples of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during pre-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.10(a&b). CGWB reported a mximum value of 4.35 mg/L F in Jabalpur (CGWB, 2001). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of chloride and sulphate falls within the desirable limit for all the samples. The values of fluoride even exceed the maximum permissible limit in 12% of the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Jabalpur indicates bacterial contamination in 50% of the samples during pre-monsoon season (Table 5.6.14). Seven samples even exceed the permissible limit for drinking water and are not suitable for drinking water. One sample even shows faecal contamination.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Jabalpur are given in Tables 5.6.15 and 5.6.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.6.17 to 5.2.24 and graphically shown in Fig. 5.6.11 to 5.6.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Jabalpur ranges from 4 to 6850 µg/L during pre-monsoon season (Table 5.6.15) and 115 to 26085 µg/L during post-monsoon season (Table 5.6.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.6.11. The Bureau of Indian Standards has recommended 300 µg/L as the desirable limit and 1000 µg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 1270 during pre-monsoon season (Table 5.6.15) and 1248 µg/L during post-monsoon season (Table 5.6.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.6.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 52 of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while24% of the samples even exceed the maximum permissible limit of 300 µg/L during both pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 15 μg/L during pre-monsoon season (Table 5.6.15) and 102 μg/L during post-monsoon season (Table 5.6.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.6.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Jabalpur, all the samples falls within the desirable limit during pre-monsoon while only one sample exceeds the desirable limit during post - monsoon (Table 5.6.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 10μg/L during pre-monsoon season (Table 5.6.15) and 12 μg/L during post-monsoon season (Table 5.6.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.6.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jabalpur, all the samples fall well within the desirable limit for drinking water (Table 5.6.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 35 μg/L during pre-monsoon season (Table 5.6.15) and 42 μg/L during post-monsoon season (Table 5.6.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.6.16. The Bureau of Indian Standards has prescribed

50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Jabalpur, 100% of the samples fall within the permissible limit during both the sasons and is safe for drinking water (Table 5.6.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 2 to 11μg/L during pre-monsoon season (Table 5.6.15) and 2.8 to 7.9 μg/L during post-monsoon season (Table 5.6.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.6.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Jabalpur, 88% of the samples are found within the permissible limit during pre-monsoon season (Table 5.6.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 3 to 500 μg/L during pre-monsoon season (Table 5.6.15) and 29 to 2235 μg/L during post-monsoon season (Table 5.6.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.6.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jabalpur, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (28% samples), manganese (24% samples), nickel (52% samples), and cadmium (12% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Jabalpur all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.6.25 and 5.7.26 Out of the Seven chlorinated pesticides analysed, Three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of thesepesticides were within the permissible limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Jabalpur.

## 5.6.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Jabalpur are given in Table 5.6.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Jabalpur vary widely from 258 to 1731µS/cm during pre-monsoon season and 226 to 1498 µS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.58 to 3.13 during pre-monsoon season and 0.47 to2.84 during post-monsoon season. The sodium percentage in the study area was found to vary from 16 to 55 % during pre-monsoon season and 14 to 59% during post-monsoon season. None of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

# 5.6.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.6.28 and 5.6.29.

# Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Jabalpur have been plotted on trilinear diagram for both the surveys (Fig. 5.6.19 and

5.6.20) and results have been summarized in Table 5.6.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Only one sample belongs to Na-K-Cl-$SO_4$ hydrochemical facies in pre-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Jabalpur have been plotted on Chadha' diagram (Fig. 5.6.21 and 5.6.22) and results have been summarized in Table 5.6.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Only one sample belongs to Na-K-Cl-$SO_4$ hydrochemical facies in both pre-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.6.23 and 5.6.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Only one sample belongs to Na-K-Cl-$SO_4$ hydrochemical facies in pre-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Jabalpur has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.6.25 and 5.6.26) and the results have been summarized in Table 5.6.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Jabalpur falls under water types C3-S1 and C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Jabalpur has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.6.29. It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and low alkalinity water as per alkalinity classification.

# 5.7 Nagpur

## 5.7.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Nagpur were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.7.1. The details of sampling locations and source and depth wise distribution are given in Table 5.7.1 and 5.7.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.7.3 and 5.7.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.7.5 to 5.7.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.7.2 to 5.7.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Nagpur are mostly confined within the range 7.1 to 8.0 during pre-monsoon season and 7.0 to 8.3 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 322 to 3100 μS/cm during pre-monsoon season and 280 to 2828 μS/cm during post-monsoon season with about 68 % samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 3100 μS/cm was observed at Nara during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 206 to 1984 mg/L during pre-monsoon season and 179 to 1810 mg/L during post-monsoon season indicating high mineralization in the area. More than 84 % of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during pre-monsoon season and 76% during post-monsoon season (Table 5.7.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 106 to 432 mg/L during pre-monsoon season and 92 to 412 mg/L during post-monsoon season. 8% and 20% samples exceed the desirable limit of 200 mg/L during pre- and post-monsoon seasons respectively. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 77 to 873 mg/L during pre-monsoon season and 68 to 810 mg/L during post-monsoon season. About 52% of the samples of the metropolitan city of Nagpur fall within the desirable limit of 300 mg/L while 40% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 8% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.7.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 19 to 241 and 2.4 to 83 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 17 to 234 mg/L and 3 to 82 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.5(a&b) and 5.7.6(a&b) respectively.

The concentration of sodium in the study area varies from 21 to 274 mg/L during pre-monsoon season and 17 to 244 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Nagpur varies from 0.2 to 18 mg/L during pre-monsoon season and 0.7 to 18 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 12% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 11 to 364 mg/L during pre-monsoon season and 12 to 324 mg/L during post-monsoon season. More than 92% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.7.10). Only 8% sample of the city exceeds the desirable limit but well within permissible limit during both pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 9.5 to 534 mg/L during pre-monsoon season and 8 to 500 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Nagpur, 92% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.7.11) during both pre- and post monsoon seasons Only one sample exceeds the maxium permissible limit of 400 mg/L during both the seasons.The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Nagpur varies from 0.4 to 172 mg/L during pre-monsoon season and 0.1 to 151mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 72% of the samples fall within the desirable limit of 45 mg/L while only 4% sample exceed the maximum permissible limit of 100 mg/L (Table 5.7.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Nagpur is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.42 mg/L during pre-monsoon season and 0.01 to 1.19mg/L during post-monsoon season. None of of the sample exceed the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of hardness values exceeds the maximum permissible limit in about 8% of the samples, sulphate and nitrate concentrations exceed the maximum permissible limit in 4% of the samples. The alkalinity values falls within the desiravble limits for all the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Nagpur indicates bacterial contamination at few locations (Table 5.7.14). Two samples even exceed the permissible limit for drinking water and are not suitable for drinking water.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Nagpur are given in Tables 5.7.15 and 5.7.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.7.17 to 5.2.24 and graphically shown in Fig. 5.7.11 to 5.7.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Nagpur ranges from 201 to 14875μg/L during pre-monsoon season (Table 5.7.15) and 170 to 10683 μg/L during post-monsoon season (Table 5.7.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.7.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 830 during pre-monsoon season (Table 5.7.15) and 896 µg/L during post-monsoon season (Table 5.7.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.7.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 80% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 8% of the samples even exceed the maximum permissible limit of 300 µg/L during both pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 421 µg/L during pre-monsoon season (Table 5.7.15) and 49 µg/L during post-monsoon season (Table 5.7.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.7.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limit and 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Nagpur, 88% of the samples falls within the desirable limit during pre-monsoon season (Table 5.7.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 13 μg/L during pre-monsoon season (Table 5.7.15) and 14 μg/L during post-monsoon season (Table 5.7.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.7.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Nagpur, almost all the samples fall well within the desirable limit for drinking water (Table 5.7.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 201 μg/L during pre-monsoon season (Table 5.7.15) and 93 μg/L during post-monsoon season (Table 5.7.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.7.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Nagpur, 80% of the samples fall within the permissible limit during pre-monsoon seasons and remaining 20% of the samples exceed the permissible limit in pre- monsoon seasons and not safe for drinking water (Table 5.7.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 11 μg/L during pre-monsoon season (Table 5.7.15) and 5 to 16 μg/L during post-monsoon season (Table 5.7.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.7.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Nagpur, 92% of the samples are found within the permissible limit during pre-monsoon season (Table 5.7.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 21 to 3100 μg/L during pre-monsoon season (Table 5.7.15) and 33 to 2670 μg/L during post-monsoon season (Table 5.7.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.7.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Nagpur, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (52% samples), manganese (8% samples), nickel (84% samples), lead (20% samples) and cadmium (8% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Nagpur, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.7.25 and 5.7.26 Out of the seven chlorinated pesticides analysed, three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of these pesticides were within the permissible limits. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Nagpur.

## 5.7.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Nagpur are given in Table 5.7.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Nagpur vary widely from 322 to 3100 μS/cm during pre-monsoon season and 280 to 2828 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.84 to 1.32 during pre-monsoon season and 0.83 to 1.32 during post-monsoon season. The sodium percentage in the study area was found to vary from 13.3 to 84.3 % during pre-monsoon season and -12.4 to 86.8 during post-monsoon season. About 12% of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) – (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, except Chikli Layout site, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.7.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.7.28 and 5.7.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Nagpur have been plotted on trilinear diagram for both the surveys (Fig. 5.7.19 and 5.7.20) and results have been summarized in Table 5.7.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Nagpur have been plotted on Chadha' diagram (Fig. 5.7.21 and 5.7.22) and results have been summarized in Table 5.7.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.7.23 and 5.7.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Nagpur has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.7.25 and 5.7.26) and the results have been summarized in Table 5.7.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Nagpur falls under water types C3-S1 followed by C2-S1. Few samples also belong to C3-S2, C3-S3 and C4-S1 type. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected**.**

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Nagpur has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.7.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low salinity water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.8 Nasik

## 5.8.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Nasik were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.8.1. The details of sampling locations and source and depth wise distribution are given in Table 5.8.1 and 5.8.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.8.3 and 5.8.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.8.5 to 5.8.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.8.2 to 5.8.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Nasik are mostly confined within the range 6.7 to 8.0 during pre-monsoon season and 6.6 to 7.7 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 681 to 2610 μS/cm during pre-monsoon season and 605 to 1853 μS/cm during post-monsoon season with about 60% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2610 μS/cm was observed at Kotam Village during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 436 to 1670 mg/L during pre-monsoon season and 387 to 1186 mg/L during post-monsoon season indicating mineralization in the area. More than 92% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during pre-monsoon season (Table 5.8.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 113 to 530 mg/L during pre-monsoon season and 104 to 470 mg/L during post-monsoon season. About 80% of the samples exceed the desirable limit of 200 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 126 to883 mg/L during pre-monsoon season and 111 to 614 mg/L during post-monsoon season. About 40% of the samples of the metropolitan city of Nasik fall within the desirable limit of 300 mg/L while 56% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and only 4% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.8.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 43 to 287 and 4.5 to 40 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 39 to 195 mg/L and 3.4 to 33 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.5(a&b) and 5.8.6(a&b) respectively.

The concentration of sodium in the study area varies from 31 to 194 mg/L during pre-monsoon season and 27 to 146 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Nasik varies from 0.2 to 29 mg/L during pre-monsoon season and 0.1 to 24 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 8% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 31 to 549 mg/L during pre-monsoon season and 26 to 338 mg/L during post-monsoon season. Ninty six of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.8.10) and only 4% sample exceed the desirable limit but are well within the maximum permissible limit of 1000 mg/L in both the seasons. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 31 to 237 mg/L during pre-monsoon season and 25 to 213 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Nasik, 96% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.8.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Nasik varies from 0.4 to 167 mg/L during pre-monsoon season and 0.1 to 137 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 52% of the samples fall within the desirable limit of 45 mg/L while only 4% sample exceed the maximum permissible limit of 100 mg/L (Table 5.8.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Nasik is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.45 mg/L during pre-monsoon season and 0.01 to 1.32 mg/L during post-monsoon season. No sample of the metropolitan city exceed the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the values of total hardness, calcium, and nitrate exceed the maximum permissible limit prescribed for drinking water. The violation of

BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Nasik indicates bacterial contamination at few locations (Table 5.8.14). Five samples even exceed the permissible limit for drinking water and are not suitable for drinking water. However, no sample indicates faecal contamination in any of the samples.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Nasik are given in Tables 5.8.15 and 5.8.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.8.17 to 5.2.24 and graphically shown in Fig. 5.8.11 to 5.8.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Nasik ranges from 216 to 7009 μg/L during pre-monsoon season (Table 5.8.15) and 14 to 2754 μg/L during post-monsoon season (Table 5.8.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.8.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 756 during pre-monsoon season (Table 5.8.15) and 317 µg/L during post-monsoon season (Table 5.8.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.8.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 92% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 4% of the samples exceed the desirable limit but are within the maximum permissible limit while 4% of the samples even exceed the maximum permissible limit of 300 µg/L during pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 39 µg/L during pre-monsoon season (Table 5.8.15) and 213 µg/L during post-monsoon season (Table 5.8.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.8.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Nasik, almost all the samples fall within the desirable limit during both pre- and post-monsoon seasons (Table 5.8.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies at most of the places. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 81 μg/L during pre-monsoon season (Table 5.8.15) and 160 μg/L during post-monsoon season (Table 5.8.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.8.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Nasik, more than 90% of the samples fall well within the desirable limit for drinking water (Table 5.8.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Interconversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 84 μg/L during pre-monsoon season (Table 5.8.15) and 110 μg/L during post-monsoon season (Table 5.8.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.8.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Nasik, more than 90% of the samples fall within the permissible limits during both pre- and post-monsoon seasons and remaining 8% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.8.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 6 to 16 μg/L during pre-monsoon season (Table 5.8.15) and 3 to 15 μg/L during post-monsoon season (Table 5.8.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.8.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Nasik, 64% of the samples are found within the permissible limit during pre-monsoon season (Table 5.8.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 33 to 5810 μg/L during pre-monsoon season (Table 5.8.15) and 41 to 7850 μg/L during post-monsoon season (Table 5.8.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.8.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Nasik, no sample exceed the maximum permissible limit prescribed for drinking water.

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (28% samples), manganese (4% samples), nickel (40% samples), chromium (8% samples), lead (8% samples) and cadmium (36% samples) during pre-monsoon season. Almost similar trend was observed during post-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Nasik, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.8.25 . and 5.8.26 Out of the seven chlorinated pesticides analysed, no pesticides have been detected in the ground water of the metropolitan city. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Nasik.

## 5.8.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Nasik are given in Table 5.8.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Nasik vary widely from -681 to 2610 µS/cm during pre-monsoon season and 605 to 1853 µS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.81 to 3.60 during pre-monsoon season and 0.74 to 3.33 during post-monsoon season. The sodium percentage in the study area was found to vary from 17.9 to 55.7 during pre-monsoon season and 17.3 to 54.7 during post-monsoon season. No sample of the city exceeds the recommended value of 60% during both pre- and post-monsoon seasons and the water is safe for irrigation purpos.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. In the present study, the RSC values indicate that ground water of the city is free from residual sodium carbonate hazard.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.8.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.8.28 and 5.8.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Nasik have been plotted on trilinear diagram for both the surveys (Fig. 5.8.19 and 5.8.20) and results have been summarized in Table 5.8.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Nasik have been plotted on Chadha' diagram (Fig. 5.8.21 and 5.8.22) and results have been summarized in Table 5.8.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.8.23 and 5.8.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Nasik has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.8.25 and 5.8.26) and the results have been summarized in Table 5.8.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Nasik falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Nasik has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.8.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low salinity water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

## 5.9 Pune

## 5.9.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Pune were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.9.1. The details of sampling locations and source and depth wise distribution are given in Table 5.9.1 and 5.9.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.9.3 and 5.9.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.9.5 to 5.9.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.9.2 to 5.9.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Pune are mostly confined within the range 7.1 to 8.0 during pre-monsoon season and 7.1 to 8.0 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 79 to 2630 µS/cm during pre-monsoon season and 74 to 2423 μS/cm during post-monsoon season with about 20% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2630 μS/cm was observed at CGWB office during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 51 to 1683 mg/L during pre-monsoon season and 47 to 1551 mg/L during post-monsoon season indicating high mineralization in the area. More than 30% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.9.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 19 to 403 mg/L during pre-monsoon season and 17 to350 mg/L during post-monsoon season. Almost all the samples exceed the desirable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 23 to 855 mg/L during pre-monsoon season and 24 to 793 mg/L during post-monsoon season. About 76 % of the samples of the metropolitan city of Pune fall within the desirable limit of 300 mg/L while20% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 4 % sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.9.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 5.6 to 76 and 2.1 to 41 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 6.2 to 67 mg/L and 2.1 to 31 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.5(a&b) and 5.9.6(a&b) respectively.

The concentration of sodium in the study area varies from 3.8 to 158 mg/L during pre-monsoon season and 3.2 to 147 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Pune varies from 0.1 to 28 mg/L during pre-monsoon season and 0.1 to 18 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 8% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 5.5 to 299mg/L during pre-monsoon season and 3.9to 278 mg/L during post-monsoon season. More than 96-% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.9.10). None of the sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 3 to 216 mg/L during pre-monsoon season and 2 to 201mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Pune, 96% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.9.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Pune varies from 0.4 to 321mg/L during pre-monsoon season and 0.1to 278 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 92% of the samples fall within the desirable limit of 45 mg/L while only one sample exceed the maximum permissible limit of 100 mg/L (Table 5.9.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Pune is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.38 mg/L during pre-monsoon season and 0.01to 1.21mg/L during post-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that hardness values exceeds the maximum permissible limit in about 4% of the samples while nitrate concentrations exceed the maximum permissible limit in 4% of the samples . The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Pune indicates bacterial contamination at 12 locations (Table 5.9.14). Six samples even exceed the permissible limit for drinking water and are not suitable for drinking water.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Pune are given in Tables 5.9.15 and 5.9.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.9.17 to 5.2.24 and graphically shown in Fig. 5.9.11 to 5.9.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Pune ranges from 65 to 1511 μg/L during pre-monsoon season (Table 5.9.15) and 59 to 1651 μg/L during post-monsoon season (Table 5.9.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.9.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 2057 during pre-monsoon season (Table 5.9.15) and 1153 μg/L during post-monsoon season (Table 5.9.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.9.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 92% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 8% of the samples even exceed the maximum permissible limit of 300 µg/L during pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 57µg/L during pre-monsoon season (Table 5.9.15) and 19 µg/L during post-monsoon season (Table 5.9.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.9.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Pune, 96% of the samples falls within the desirable limit during pre-monsoon seasons (Table 5.9.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 18µg/L during pre-monsoon season (Table 5.9.15) and 61µg/L during post-monsoon season (Table 5.9.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.9.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Pune, almost all the samples fall well within the desirable limit for drinking water (Table 5.9.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 64 μg/L during pre-monsoon season (Table 5.9.15) and 49 μg/L during post-monsoon season (Table 5.9.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.9.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Pune, 92% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining 8% of the samples exceed the permissible limit in pre-monsoon (Table 5.9.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 18μg/L during pre-monsoon season (Table 5.9.15) and 4 to 10 μg/L during post-monsoon season (Table 5.9.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.9.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Pune, 96% of the samples are found within the permissible limit during pre-monsoon season (Table 5.9.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 7 to 1490 μg/L during pre-monsoon season (Table 5.9.15) and 11 to 1784 μg/L during post-monsoon season (Table 5.9.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.9.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Pune, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron

(8% samples), manganese (8% samples), nickel (4% samples), lead (8% samples) and cadmium (4% samples) during pre-monsoon season**.**

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Pune, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.9.25 . and 5.9.26 Out of the seven chlorinated pesticides analysed, one pesticides (Aldrin, ) have been detected at few locations in the ground water of the metropolitan city. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Pune.

# 5.9.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity

- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Pune are given in Table 5.9.27.

# Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Pune vary widely from 79 to 2630 μS/cm during pre-monsoon season and 74 to 2423 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.31 to 2.34 during pre-monsoon season and 0.26 to 2.27 during post-monsoon season. The sodium percentage in the study area was found to vary from 13.7 to 40.9 % during pre-monsoon season and -12.7 to 40.8 during post-monsoon season. None of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons.

## Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.9.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.9.28 and 5.9.29.

# Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Pune have been plotted on trilinear diagram for both the surveys (Fig. 5.9.19 and 5.9.20) and results have been summarized in Table 5.9.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Pune have been plotted on Chadha' diagram (Fig. 5.9.21 and 5.9.22) and results have been summarized in Table 5.9.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.9.23 and 5.9.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Pune has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.9.25 and 5.9.26) and the results have been summarized in Table 5.9.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Pune falls under water types C3-S1 followed by C1-S1 and C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Pune has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.9.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification

## 5.10 Bangalore

## 5.10.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Bangalore were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.10.1. The details of sampling locations and source and depth wise distribution are given in Table 5.10.1 and 5.10.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.10.3 and 5.10.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.10.5 to 5.10.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.10.2 to 5.10.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Bangalore are mostly confined within the range 7.3 to 8.5 during pre-monsoon season and 6.3 to 7.7 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 281 to 4270 μS/cm during pre-monsoon season and 279 to 3970 μS/cm during post-monsoon season with about 32% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 4270 μS/cm was observed at Krishna Raja Puram during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 180 to 2733 mg/L during pre-monsoon season and 179 to 2541 mg/L during post-monsoon season indicating high mineralization in the area. Only 4% of the samples exceed the maximum permissible limit both during pre- and post-monsoon season (Table 5.10.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 95 to 659 mg/L during pre-monsoon season and 95 to 588 mg/L during post-monsoon season. About 64% of the samples fall within the desirable limit of 200 mg/L while 36% of the samples exceed the desirable limit but are well within the maximum permissible limit of 600 mg/L during pre-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 55 to 1345 mg/L during pre-monsoon season and 50 to 1241 mg/L during post-monsoon season. About 72% of the samples of the metropolitan city of Bangalore fall within the desirable limit of 300 mg/L while 20% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 8% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.10.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 9 to 427 and 2 to 68mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 8.2 to 397 mg/L and 1.4 to 6.1 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.5(a&b) and 5.10.6(a&b) respectively.

The concentration of sodium in the study area varies from 24 to 365 mg/L during pre-monsoon season and 21 to 345 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Bangalore varies from 1.6 to 18 mg/L during pre-monsoon season and 1.2 to 14 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 12% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 10 to 769 mg/L during pre-monsoon season and 11 to 721 mg/L during post-monsoon season. More than 84% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.10.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 3 to 232 mg/L during pre-monsoon season and 2.3 to 217 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Bangalore, 96% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.10.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Bangalore varies from 0.1 to 308 mg/L during pre-monsoon season and 0.1 to 287 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 80% of the samples fall within the desirable limit of 45 mg/L while only 8% sample exceed the maximum permissible limit of 100 mg/L during pre-monsoon season (Table 5.10.12). Similar trend was observed during post-monsoon season. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Bangalore is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.10 mg/L during pre-monsoon season and 0.01 to 0.76 mg/L during post-monsoon season. No sample of the metropolitan city exceed the maximum permissible limit of 1.5

mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of total dissolved solids values exceeds the maximum permissible limit in about 4% of the samples, hardness values exceed the maximum permissible limit in 8% of the samples while nitrate concentrations exceed the maximum permissible limit in 8% of the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Bangalore indicates bacterial contamination at three locations (Table 5.10.14) but the values are within the permissible limits prescribed for drinking water.

## Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Bangalore are given in Tables 5.10.15 and 5.10.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.10.17 to 5.2.24 and graphically shown in Fig. 5.10.11 to 5.10.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Bangalore ranges from 21 to 25380 µg/L during pre-monsoon season (Table 5.10.15) and 92 to 23040 µg/L during post-monsoon season (Table 5.10.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.10.11. The Bureau of Indian Standards has recommended 300 µg/L as the desirable limit and 1000 µg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 737 during pre-monsoon season (Table 5.10.15) and 2798 µg/L during post-monsoon season (Table 5.10.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.10.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 24% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 32% of the samples even exceed the maximum permissible limit of 300 µg/L during pre-post-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 102 µg/L during pre-monsoon season (Table 5.10.15) and 93 µg/L during post-monsoon season (Table 5.10.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.10.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Bangalore, almost all the samples falls within the desirable limit during both pre- and post-monsoon seasons (Table 5.10.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 63 µg/L during pre-monsoon season (Table 5.10.15) and 250 µg/L during post-monsoon season (Table 5.10.16).. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.10.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Bangalore, about 96% of the samples fall well within the desirable limit for drinking water (Table 5.10.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 122 µg/L during pre-monsoon season (Table 5.10.15) and 166 µg/L during post-monsoon season (Table 5.10.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.10.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Bangalore, 80% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining about 20% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.10.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 1 to 13 μg/L during pre-monsoon season (Table 5.10.15) and 6 to 42 μg/L during post-monsoon season (Table 5.10.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.10.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Bangalore, 84% of the samples are found within the permissible limit during pre-monsoon season (Table 5.10.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 64 to 7510 μg/L during pre-monsoon season (Table 5.10.15) and 54 to 13940 μg/L during post-monsoon season (Table 5.10.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.10.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Bangalore, all the samples were found within the permissible limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (40% samples), manganese (32% samples), nickel (68% samples), chromium (4% samples), lead (20% samples) and cadmium (16% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Bangalore, all the twenty five samples were analysed for organo-chlorinated pesticides

(Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.10.25 and 5.10.26 Out of the seven chlorinated pesticides analysed, three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of these pesticides were within the permissible limits**.** The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Bangalore.

## 5.10.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Bangalore are given in Table 5.10.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Bangalore vary widely from 281 to 4270 μS/cm during pre-monsoon season and 279 to 3970 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.88 to 4.33 during pre-monsoon season and 0.86 to 4.26 during post-monsoon season. The sodium percentage in the study area was found to vary from 24.1 to 65.6% during pre-monsoon season and 21.5 to 69.1 during post-monsoon season. Only two samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

## Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.10.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.10.28 and 5.10.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Bangalore have been plotted on trilinear diagram for both the surveys (Fig. 5.10.19 and 5.10.20) and results have been summarized in Table 5.10.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ followed by Ca-Mg-Cl-$SO_4$. Few samples of the metropolitan city also falls under Na-K-$HCO_3$ and Na-K-Cl-$SO_4$ hydrochemical facies.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Bangalore have been plotted on Chadha' diagram (Fig. 5.10.21 and 5.10.22) and results have been summarized in Table 5.10.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ followed by Ca-Mg-Cl-$SO_4$. Few samples of the metropolitan city also falls under Na-K-$HCO_3$ and Na-K-Cl-$SO_4$ hydrochemical facies.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.10.23 and 5.10.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ followed by Ca-Mg-Cl-$SO_4$. Few samples of the metropolitan city also falls under Na-K-$HCO_3$ and Na-K-Cl-$SO_4$ hydrochemical facies.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Bangalore has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.10.25 and 5.10.26) and the results have been summarized in Table 5.10.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Bangalore falls under water types C2-S1 followed by C3-S1 type.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Bangalore has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.10.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and low alkalinity water as per alkalinity classification

# 5.11 Hyderabad

## 5.11.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Hyderabad were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.11.1. The details of sampling locations and source and depth wise distribution are given in Table 5.11.1 and 5.11.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.11.3 and 5.11.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.11.5 to 5.11.13 and distribution maps are presented in the form of contour diagrams in

Figs. 5.11.2 to 5.11.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Hyderabad are mostly confined within the range 7.0 to 7.2 during pre-monsoon season and 6.9 to 7.9during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 566 to 3789 μS/cm during pre-monsoon season and 493 to 3072 μS/cm during post-monsoon season with about 80% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 3789 μS/cm was observed at Dilsukh Nagar during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 362 to 2425 mg/L during pre-monsoon season and 316 to 1966 mg/L during post-monsoon season indicating high mineralization in the area. About 90% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.11.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 124 to 610 mg/L during pre-monsoon season and 111 to 534 mg/L during post-monsoon season. About 90% of the samples exceed the desirable limit of 200 mg/L during both pre-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 124 to 852 mg/L during pre-monsoon season and 113 to 750 mg/L during post-monsoon season. About 20% of the samples of the metropolitan city of

Hyderabad fall within the desirable limit of 300 mg/L while72% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 8% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.11.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 35 to 256 and 9 to 62 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 32 to 233 mg/L and 1 to 41 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.5(a&b) and 5.11.6(a&b) respectively.

The concentration of sodium in the study area varies from 41 to 375 mg/L during pre-monsoon season and 35 to 234 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Hyderabad varies from 0.7 to 36 mg/L during pre-monsoon season and 0.5 to 28 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 20% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 44 to 396 mg/L during pre-monsoon season and 39 to 313 mg/L during post-monsoon season. More than 90% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.11.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 28 to 354 mg/L during pre-monsoon season and 21 to 280 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Hyderabad, 92% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.11.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Hyderabad varies from 24 to 210 mg/L during pre-monsoon season and 21 to 192 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 16% of the samples fall within the desirable limit of 45 mg/L while only 12% sample exceed the maximum permissible limit of 100 mg/L during pre-monsoon season (Table 5.11.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.9(a&b). CGWB reported a maximum value of 300 mg/L at Sirinagar in L.B.Nagar municipal area (CGWB, 2000).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Hyderabad is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.55 to 1.80 mg/L during pre-monsoon season and 0.42 to 2.40 mg/L during post-monsoon season. About 76% of the samples of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during pre-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.11.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man’s activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of total dissolved solids and alkalinity values exceeds the maximum permissible limit in only one sample, nitrate concentrations exceed the maximum permissible limit in 12% of the samples while fluoride content exceeds the maximum permissible limit 76% of the samples during pre-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Hyderabad indicates bacterial contamination in more than 50% of the samples (Table 5.11.14). Four samples even exceed the permissible limit for drinking water and are not suitable for drinking water during pre-monsoon season.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Hyderabad are given in Tables 5.11.15 and 5.11.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.11.17 to 5.2.24 and graphically shown in Fig. 5.11.11 to 5.11.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Hyderabad ranges from 69 to 611 μg/L during pre-monsoon season (Table 5.11.15) and 36 to 489 μg/L during post-monsoon season (Table 5.11.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.11.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 568 μg/L during pre-monsoon season (Table 5.11.15) and 704 μg/L during post-monsoon season (Table 5.11.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.11.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 88% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L while 4% of the samples even exceed the maximum permissible limit of 300 μg/L during pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 22 μg/L during pre-monsoon season (Table 5.11.15) and 17 μg/L during post-monsoon season (Table 5.11.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.11.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Hyderabad, all the samples falls within the desirable limit during both pre- and post-monsoon seasons (Table 5.5.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 17 μg/L during pre-monsoon season (Table 5.11.15) and 39 μg/L during post-monsoon season (Table 5.11.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.11.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Hyderabad, all the samples fall well within the desirable limit for drinking water (Table 5.11.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 77 μg/L during pre-monsoon season (Table 5.11.15) and 61 μg/L during post-monsoon season (Table 5.11.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.11.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Hyderabad, 92% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining 8% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.11.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 4 to 20 μg/L during pre-monsoon season (Table 5.11.15) and 5 to 14 μg/L during post-monsoon season (Table 5.11.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.11.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Hyderabad, 64% of the samples are found within the permissible limit during pre-monsoon season (Table 5.11.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 17 to 6790 μg/L during pre-monsoon season (Table 5.11.15) and 44 to 6290 μg/L during post-monsoon season (Table 5.11.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.11.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Hyderabad, all the samples were found within the permissible limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for manganese (4% samples), nickel (68% samples), lead (8% samples) and cadmium (36% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Hyderabad, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Dieldrine,Carbamate, 2,4-D , DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.11.25 and 5.11.26 Out of the seven chlorinated pesticides analysed, one pesticides (Aldrin, ) have been detected at few locations in the ground water of the metropolitan city. The concentration of aldrin was found to exceed the permissible limit prescribed for drinking water at location no. 25. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Hyderabad.

# 5.11.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Hyderabad are given in Table 5.11.27.

# Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Hyderabad vary widely from 566 to 3789 μS/cm during pre-monsoon season and 493 to 3072 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 1.01 to 5.58 during pre-monsoon season and 0.92 to 3.71 during post-monsoon season. The sodium percentage in the study area was found to vary from 19.1 to 50.8% during pre-monsoon season and 20.0 to 50.6 during post-monsoon season. No samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to

deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

# 5.11.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.11.28 and 5.11.29.

# Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Hyderabad have been plotted on trilinear diagram for both the surveys (Fig. 5.11.19 and 5.11.20) and results have been summarized in Table 5.11.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$.

# Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Hyderabad have been plotted on Chadha' diagram (Fig. 5.11.21 and 5.11.22) and results have been summarized in Table 5.11.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$.

# Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.11.23 and 5.11.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Hyderabad has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.11.25 and 5.11.26) and the results have been summarized in Table 5.11.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Hyderabad falls under water types C3-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Hyderabad has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.11.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city of fall under normal water to low salinity water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline water as per alkalinity classification**.**

# 5.12 Vishakhapatnam

## 5.12.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Vishakhapatnam were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.12.1. The details of sampling locations and source and depth wise distribution are given in Table 5.12.1 and 5.12.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.12.3 and 5.12.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.12.5 to 5.12.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.12.2 to 5.12.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Vishakhapatnam are mostly confined within the range 7.5 to 8.0 during pre-monsoon season and 6.1 to 8.1 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 793 to 11770 μS/cm during pre-monsoon season and 727 to 11560 μS/cm during post-monsoon season with about 68% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 11770 μS/cm was observed at Post Office (Port Area) during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 508 to 7533 mg/L during pre-monsoon season and 465 to 7398 mg/L during post-monsoon season indicating high mineralization in the area. More than 92% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre-monsoon seasons (Table 5.12.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 180 to 1326 mg/L during pre-monsoon season and 161 to 715 mg/L during post-monsoon season. About 80% of the samples exceed the desirable limit of 200 mg/L during both pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 160 to 1146 mg/L during pre-monsoon season and 176 to 1502 mg/L during post-monsoon season. About 40% of the samples of the metropolitan city of Vishakhapatnam fall within the desirable limit of 300 mg/L while 56% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and 4% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.12.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 35 to 420 and 8.3 to 41mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 30 to 401 mg/L and 3.9 to 122 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.5(a&b) and 5.12.6(a&b) respectively.

The concentration of sodium in the study area varies from 48 to 2072 mg/L during pre-monsoon season and 41 to 1928 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Vishakhapatnam varies from 0.8 to 186 mg/L during pre-monsoon season and 0.4 to 138 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 16% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 36 to 2079 mg/L during pre-monsoon season and 41 to 3514 mg/L during post-monsoon season. More than 80% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.12.10). Only one sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 27 to 825 mg/L during pre-monsoon season and 21 to 600 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Vishakhapatnam, 88% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.12.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Vishakhapatnam varies from 16 to 185 mg/L during pre-monsoon season and 0.4 to 211 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 36% of the samples fall within the desirable limit of 45 mg/L while 24% of the samples exceed the maximum permissible limit of 100 mg/L (Table 5.12.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Vishakhapatnam is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.58 mg/L during pre-monsoon season and 0.01 to 1.32 mg/L during post-monsoon season. Only one sample of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.12.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man’s activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of total dissolved solids exceed the maximum permissible limit in 8% of the samples, alkalinity, hardness, chloride, sulphate and fluoride values exceed the maximum permissible limit in 4% of the samples while nitrate content exceeds the maximum permissible limit in 24% of the samples. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Vishakhapatnam indicates bacterial contamination in about 50% of the samples (Table 5.12.14). Seven samples even exceed the permissible limit for drinking water and are not suitable for drinking water.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Vishakhapatnam are given in Tables 5.12.15 and 5.12.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.12.17 to 5.2.24 and graphically shown in Fig. 5.12.11 to 5.12.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Vishakhapatnam ranges from 6 to 4986 μg/L during pre-monsoon season (Table 5.12.15) and 15 to 4937 μg/L during post-monsoon season (Table 5.12.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.12.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 55900 during pre-monsoon season (Table 5.12.15) and 57600 μg/L during post-monsoon season (Table 5.12.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.12.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 88% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L while 8% of the samples even exceed the maximum permissible limit of 300 μg/L during both pre- and post-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 45 μg/L during pre-monsoon season (Table 5.12.15) and 24 μg/L during post-monsoon season (Table 5.12.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.12.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limitsand 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Vishakhapatnam, all the samples falls within the desirable limit during both pre- and post-monsoon seasons (Table 5.5.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 30 μg/L during pre-monsoon season (Table 5.12.15) and 12 μg/L during post-monsoon season (Table 5.12.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.12.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Vishakhapatnam, almost all the samples fall well within the desirable limit for drinking water (Table 5.12.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, $Cr(3+)$, being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 129 μg/L during pre-monsoon season (Table 5.12.15) and 101 μg/L during post-monsoon season (Table 5.12.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.12.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Vishakhapatnam, 88% of the samples fall within the permissible limit and remaining 12% of the samples exceed the permissible limit during pre-monsoon sason and not safe for drinking water (Table 5.12.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 2 to 135 μg/L during pre-monsoon season (Table 5.12.15) and 4 to 120 μg/L during post-monsoon season (Table 5.12.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.12.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Vishakhapatnam, 12% of the samples are found within the permissible limit during pre-monsoon season (Table 5.12.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 6 to 16280 μg/L during pre-monsoon season (Table 5.12.15) and 17 to 10464 μg/L during post-monsoon season (Table 5.12.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.12.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Vishakhapatnam, almost all the samples were found within the permissible limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (4% samples), manganese (8% samples), nickel (68% samples), lead (12% samples), cadmium (88% samples) and zinc (4% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Vishakapatnam, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.12.25 and 5.12.26 Out of the seven chlorinated pesticides analysed, one pesticides (DDT) have been detected at few locations in the ground water of the metropolitan city. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Vishakhapatnam.

# 5.12.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Vishakhapatnam are given in Table 5.12.27.

# Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Vishakhapatnam vary widely from 793 to 11770 μS/cm during pre-monsoon season and 727 to 11560 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 1.03 to 26.59 during pre-monsoon season and 0.99 to 21.63 during post-monsoon season. The sodium percentage in the study area was found to vary from 17.9 to 85.4% during pre-monsoon season and 18.5 to 60.6 during post-monsoon season. About 12% of the samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

# Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.12.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.12.28 and 5.12.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Vishakhapatnam have been plotted on trilinear diagram for both the surveys (Fig. 5.12.19 and 5.12.20) and results have been summarized in Table 5.12.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Vishakhapatnam have been plotted on Chadha' diagram (Fig. 5.12.21 and 5.12.22) and results have been summarized in Table 5.12.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.12.23 and 5.12.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Vishakhapatnam has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.12.25 and 5.12.26) and the results have been summarized in Table

5.12.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Vishakhapatnam falls under water types C3-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Vishakhapatnam has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.12.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification.

# 5.13 Patna

# 5.13.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Patna were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.13.1. The details of sampling locations and source and depth wise distribution are given in Table 5.13.1 and 5.13.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.13.3 and 5.13.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.13.5 to 5.13.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.13.2 to 5.13.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Patna are mostly confined within the range 6.9 to 7.7 during pre-monsoon season and 7.1 to 7.7 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 517 to 1422 μS/cm during pre-monsoon season and 440 to 1312 μS/cm during post-monsoon season with about 8% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 1422 μS/cm was observed at digha Police station during pre-monsoon season. Almost similar values of conductivity have been reported by CGWB (2000).

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 331 to 910 mg/L during pre-monsoon season and 282 to 840 mg/L during post-monsoon season indicating high mineralization in the area. More than 70% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.13.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 151 to 305 mg/L during pre-monsoon season and 135 to 291 mg/L during post-monsoon season. About 20% of the samples fall within the desirable limit of 200 mg/L during both pre-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 136 to 491 mg/L during pre-monsoon season and 117 to 453 mg/L during post-monsoon season. About 84% of the samples of the metropolitan city of Patna fall within the desirable limit of 300 mg/L while 16% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L and no sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.13.7). Almost similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 11 to 144 and 5.1 to 35 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 4.1 to 31mg/L and -12 to 137 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.5(a&b) and 5.13.6(a&b) respectively.

The concentration of sodium in the study area varies from 24 to 94 mg/L during pre-monsoon season and 19 to 79 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Patna varies from 0.6 to 31 mg/L during pre-monsoon season and 0.5 to 21 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, only one sample exceeds the guideline level of 10 mg/L during both pre- and post-monsoon seasons. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 6.6 to 178 mg/L during pre-monsoon season and 6 to 158 mg/L during post-monsoon season. All the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.13.10). The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 2.5 to 61 mg/L during pre-monsoon season and 2.7 to 56 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Patna, all the samples analysed fall within the desirable limit of 200 mg/L (Table 5.13.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Patna varies from 0.1 to 90 mg/L during pre-monsoon season and 0.1 to 81 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 84% of the samples fall within the desirable limit of 45 mg/L. No sample exceeds the maximum permissible limit of 100 mg/L (Table 5.13.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Patna is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.59 mg/L during pre-monsoon season and 0.01 to 1.82 mg/L during post-monsoon season. About 8% of the samples of the metropolitan city even exceed the maximum permissible limit of 1.5 mg/L during prre-monsoon season. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.13.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of fluoride exceeds the maximum permissible limit in 8% of the samples only. All other constitutenets are within maximum permissible limits. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Patna indicates bacterial contamination in about 50% of the samples (Table 5.13.14). Seven samples even exceed the permissible limit for drinking water and are not suitable for drinking water. High values of bacterial contamination has also been reported by CGWB (2000).

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Patna are given in Tables 5.13.15 and 5.13.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.13.17 to 5.2.24 and graphically shown in Fig. 5.13.11 to 5.13.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Patna ranges from 116 to 3605 μg/L during pre-monsoon season (Table 5.13.15) and 97 to 3130 μg/L during post-monsoon season (Table 5.13.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.13.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The “red rot” disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 232 during pre-monsoon season (Table 5.13.15) and 198 μg/L during post-monsoon season (Table 5.13.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.13.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 60% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L during pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 90 µg/L during pre-monsoon season (Table 5.13.15) and 914 µg/L during post-monsoon season (Table 5.13.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.13.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Patna, more than 90% of the samples fall within the desirable limit during both pre- and post-monsoon seasons (Table 5.13.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 16 µg/L during pre-monsoon season (Table 5.13.15) and 11 µg/L during post-monsoon season (Table 5.13.16**)** and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.13.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Patna, all the samples fall well within the desirable limit for drinking water (Table 5.13.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 174 µg/L during pre-monsoon season (Table 5.13.15) and 171 µg/L during post-monsoon season (Table 5.13.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.13.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Patna, 96% of the samples fall within the permissible limit during pre- and post-monsoon seasons and remaining 4% of the samples exceed the permissible limit in both the sasons and not safe for drinking water (Table 5.13.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 5 to 13 μg/L during pre-monsoon season (Table 5.13.15) and 5.2 to 12.5 μg/L during post-monsoon season (Table 5.13.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.13.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Patna, 88% of the samples are found within the permissible limit during pre-monsoon season (Table 5.13.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 5 to 858 μg/L during pre-monsoon season (Table 5.13.15) and 3 to 656 μg/L during post-monsoon season (Table 5.13.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.13.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Patna, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (20% samples), nickel (84% samples), lead (4% samples) and cadmium (12% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Patna, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.13.25 and 5.13.26 . Out of the seven chlorinated pesticides analysed, three pesticides (Aldrin, DDT Methoxychlor) have been detected at few locations in the ground water of the metropolitan city. However, concentration of these pesticides The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Patna.

# 5.13.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Patna are given in Table 5.13.27.

# Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Patna vary widely from 517 to 1422 μS/cm during pre-monsoon season and 440 to 1312 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

# Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.75 to 1.84 during pre-monsoon season and 0.70 to 1.61 during post-monsoon season. The sodium percentage in the study area was found to vary from 21.3 to 34.8% during pre-monsoon season and 21.1 to 37.4 during post-monsoon season. No samples exceed the recommended value of 60% during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all the locations.

## Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.13.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.13.28 and 5.13.29.

## Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Patna have been plotted on trilinear diagram for both the surveys (Fig. 5.13.19 and 5.13.20) and results have been summarized in Table 5.13.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Patna have been plotted on Chadha' diagram (Fig. 5.13.21 and 5.13.22) and results have been summarized in Table 5.13.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.13.23 and 5.13.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Patna has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.13.25 and 5.13.26) and the results have been summarized in Table 5.13.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Patna falls under water types C2-S1 followed by C3-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Patna has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.13.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and low alkalinity water as per alkalinity classification

# 5.14 Kochi

## 5.14.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Kochi were collected each during pre- as well as post-monsoon seasons during the year 2004 from various abstraction sources. The location of sampling sites is shown in Fig. 5.14.1. The details of sampling locations and source and depth wise distribution are given in Table 5.14.1 and 5.14.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.14.3 and 5.14.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.14.5 to 5.14.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.14.2 to 5.14.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Kochi are mostly confined within the range from 6.6 to 8.1 during pre-monsoon season and 5.1 to 7.4 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 142 to 1707 μS/cm during pre-monsoon season and 132 to 1598 μS/cm during post-monsoon season with about 20% samples having conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of1707 μS/cm was observed at Port Trust office during pre-monsoon season.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 91 to 1092 mg/L during pre-monsoon season and 84 to 1023- mg/L during post-monsoon season indicating high mineralization in the area. About 20% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during both pre- and post-monsoon seasons (Table 5.14.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 36 to 410 mg/L during pre-monsoon season and 39 to 398 mg/L during post-monsoon season. About 12% of the samples exceed the desirable limit of 200 mg/L during both pre-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.3(a&b). The high alkalinity values at few locations may be due to the action of carbonates upon the basic materials in the soil.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 41 to 536 mg/L during pre-monsoon season and 41 to 450 mg/L during post-monsoon season. About 88% of the samples of the metropolitan city of Kochi fall within the desirable limit of 300 mg/L while 12% sample crosses the desirable limit but are well within the permissible limit of 600 mg/L during pre-monsoon season (Table 5.14.7). similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.4(a&b).

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the metropolitan city, the values of calcium and magnesium range from 10 to 150 and 0.2 to 52 mg/L respectively during pre-monsoon season. During post-monsoon season, the values of calcium and magnesium vary from 10 to 139 mg/L and 2.1 to 36 mg/L respectively. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.5(a&b) and 5.14.6(a&b) respectively.

The concentration of sodium in the study area varies from 6.9 to 214 mg/L during pre-monsoon season and 5.9 to 210 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena. Ground water with such high sodium is not suitable for irrigation purpose due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water of the metropolitan city of Kochi varies from 0.5 to 17 mg/L during pre-monsoon season and 1.1 to 18 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, about 32% samples exceed the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season. Higher potassium content in ground water is indicative of ground water pollution.

The concentration of chloride varies from 6 to 355 mg/L during pre-monsoon season and 2 to 354 mg/L during post-monsoon season. More than 90% of the samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.14.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water

(BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content changes significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools and surface runoff water collected in low lying areas. The concentration of sulphate in the study area varies from 1 to 135 mg/L during pre-monsoon season and 0.5 to 93 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the metropolitan city of Kochi, 100% of the samples analysed fall within the desirable limit of 200 mg/L (Table 5.14.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in many parts of the country. The nitrate content in the metropolitan city of Kochi varies from 0.1 to 123 mg/L during pre-monsoon season and 0.1 to 91 mg/L during post-monsoon season. Distribution of nitrate in the ground water indicates that about 92% of the samples fall within the desirable limit of 45 mg/L while only 4% sample exceed the maximum permissible limit of 100 mg/L (Table 5.14.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.9(a&b).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The concentration of phosphate in the metropolitan city of Kochi is generally low at all the locations. Phosphorous is an essential plant nutrient and is extensively used as fertilizers. Phosphate gets adsorbed or fixed as aluminium or iron phosphate in acidic soils or as calcium phosphate in alkaline or neutral soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the metropolitan city varies from 0.01 to 1.4 mg/L during pre-monsoon season and 0.14 to 0.72 mg/L during post-monsoon season. No sample of the metropolitan city exceed the maximum permissible limit of 1.5 mg/L during both the seasons. The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.14.10(a&b). The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff.

Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water.

The study has clearly indicated that the concentration of all the constituents are well within the maximum permissible limits prescribed for drinking water except nitrate (only one sample). The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Kochi indicates bacterial contamination at few locations (Table 5.14.14). Two samples even exceed the permissible limit for drinking water and are not suitable for drinking water.

# Heavy Metals

The contamination of ground water by heavy metals has received great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Kochi are given in Tables 5.14.15 and 5.14.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.14.17 to 5.2.24 and graphically shown in Fig. 5.14.11 to 5.14.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Kochi ranges from 77 to 25075 μg/L during pre-monsoon season (Table 5.14.15) and 310 to 5244 μg/L during post-monsoon season (Table 5.14.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.14.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. The "red rot" disease of water caused by bacterial precipitation of hydrated oxides of ferric iron with consequent unaesthetic appearance to water, clogging of pipes, pitting of pipes and occurrence of foul smells, is due to the presence of relatively high iron in water. The concentration of iron in natural water is controlled by both physico-chemical and microbiological factors. In aqueous solutions iron form iron hydroxides. The weathering of rock and discharge of waste effluents on land are the main source of iron in ground water. Iron migrates as adsorbed to suspended matter, insoluble hydrated iron compounds, complexed to inorganic and organic ligands and also as hydrated ions. Dissolved carbon dioxide, pH and Eh of water affect the nature of aqueous iron species present in the water. In ground water iron generally occurs in two oxidation states, i.e., Ferrous ($Fe^{2+}$) and Ferric ($Fe^{3+}$) forms.

**Manganese (Mn):** The concentration of manganese recorded a maximum level of 485 during pre-monsoon season (Table 5.14.15) and 423 µg/L during post-monsoon season (Table 5.14.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.14.12. Manganese is an essential element, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. In general concentration of manganese in ground water is low due to geo-chemical control. A concentration of 100 µg/L has been recommended as a desirable limit and 300 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

It is evident from the results that 76% of the samples of the metropolitan city fall within the desirable limit of 100 µg/L while 8% of the samples even exceed the maximum permissible limit of 300 µg/L during both pre-monsoon season. High concentration of manganese at few locations may be attributed to the reducing conditions of the water and dissolution of manganese bearing minerals from the soil strata. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water.

**Copper (Cu):** The concentration of copper recorded a maximum level of 22 µg/L during pre-monsoon season (Table 5.14.15) and 556 µg/L during post-monsoon season (Table 5.14.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.14.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limitsand 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 µg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996).

In the metropolitan city of Kochi, all the samples fall within the desirable limit during both pre-monsoon seasons (Table 5.5.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life.

Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver. The industrial sources of copper that enhance the concentration in ground water include industrial effluents from electroplating units, textiles, paints and pesticides.

**Chromium (Cr):** The concentration of chromium in the study area recorded a maximum level of 10 μg/L during pre-monsoon season (Table 5.14.15) and 7 μg/L during post-monsoon season (Table 5.14.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.14.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kochi, all the samples fall well within the desirable limit for drinking water (Table 5.14.21).

The two important oxidation states of chromium in natural waters are +3 and +6. In well oxygenated waters, Cr(+6) is the thermodynamically stable species. However, Cr(3+), being kinetically stable, could persist bound to naturally occurring solids. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Municipal wastewater release considerable amount of chromium into the environment. Chromium is not acutely toxic to humans. This is due to the high stability of natural chromium complexes in abiotic matrices. In addition, the hard acid nature of chromium imparts strong affinity for oxygen donors rather than sulfur donors present in biomolecules. However, Cr(+6) is more toxic than Cr(+3) because of its high rate of adsorption through intestinal tracts. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges.

**Lead (Pb):** The concentration of lead in the study area recorded a maximum level of 48 μg/L during pre-monsoon season (Table 5.14.15) and 65 μg/L during post-monsoon season (Table 5.14.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.14.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996).

In the metropolitan city of Kochi, all the samples fall within the permissible limit during pre-monsoon season (Table 5.14.22). The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 10 μg/L during pre-monsoon season (Table 5.14.15) and 6 to13 μg/L during post-monsoon season (Table 5.14.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.14.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996).

In the metropolitan city of Kochi, all the samples are found within the permissible limit during pre-monsoon season (Table 5.14.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. Cadmium can also enter the environment from a variety of industrial applications, including mining and smelting, electroplating, and pigment and plasticizer production. The water is contaminated with cadmium by industrial discharges and leaches from land filled areas. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 12 to 327 μg/L during pre-monsoon season (Table 5.14.15) and 18 to 1625 μg/L during post-monsoon season (Table 5.14.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.14.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kochi, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (32% samples), manganese (8% samples) and nickel (44% samples) during pre-monsoon season.

# Pesticides

The synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are frequently used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. Pesticides applied to the crops may reach to surface water and later to the ground water through percolation. The pesticides not only affect taste and odour problems but also impart toxicity to the ground water.

During ground water quality assessment of the metropolitan city of Kochi, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.14.25 and 5.14.26 Out of the seven chlorinated pesticides analysed, two pesticides (Aldrin, and DDE) have been detected at few locations in the ground water of the metropolitan city. The concentration of aldrin excced the permissibl;e limit prescribed for drinking water at location 24 in pre-monsoon season. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are carcinogenic and genotoxic pollutants even at trace level. They are byproducts of petroleum processing or combustion industries. Although they are insoluble in water but, sometimes, contaminate water resources. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. However, during the present investigations no PAH has been detected in any of the ground water samples of the metropolitan city of Kochi.

## 5.14.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

- Salinity
- Relative Proportion of Sodium to other Cations (SAR)
- Residual Sodium Carbonate (RSC)
- Boron

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Kochi are given in Table 5.14.27.

## Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

The electrical conductivity values in the metropolitan city of Kochi vary widely from 142 to 1707 μS/cm during pre-monsoon season and 132 to 1598 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the metropolitan city ranged from 0.27 to 6.32 during pre-monsoon season and 0.28 to 5.60 during post-monsoon season. The sodium percentage in the study area was found to vary from 10.7 to 66.2 % during pre-monsoon season and 12.2 to 65.9 during post-monsoon season. Only one sample exceed the recommended value of 60% during pre-monsoon season and two samples during post-monsoon season s and are not suitable for irrigation purpose.

## Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^{-} + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tends to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to

deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at most of the locations.

# Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 mg/L in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant. During the present study, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

# 5.14.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.14.28 and 5.14.29.

# Piper Trilinear Classification

The chemical analysis data of all the samples collected from the metropolitan city of Kochi have been plotted on trilinear diagram for both the surveys (Fig. 5.14.19 and 5.14.20) and results have been summarized in Table 5.14.28. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Chadha's Diagram

The chemical analysis data of all the samples collected from the metropolitan city of Kochi have been plotted on Chadha' diagram (Fig. 5.14.21 and 5.14.22) and results have been summarized in Table 5.14.28. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.14.23 and 5.14.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ type followed by Ca-Mg-Cl-$SO_4$. Few samples also belong to Na-K-Cl-$SO_4$ and Na-K-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Kochi has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.14.25 and 5.14.26) and the results have been summarized in Table 5.14.28. It is evident from the results that the majority of ground water samples of the metropolitan city of Kochi falls under water types C2-S1 followed by C3-S1. Few samples also belong to C1-S1 and C3-S2.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Kochi has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.14.29**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal water type on the basis of salinity, non-sodic water as per sodicity and low alkalinity water as per alkalinity classification.

# 5.15 Ahmedabad

# 5.15.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Ahmedabad were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.1.1. The details of sampling locations and source and depth wise distribution are given in Table 5.1.1 and 5.1.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.1.3 and 5.1.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.1.5 to 5.1.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.1.2 to 5.1.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Ahmedabad mostly fall within the range 7.15 to 8.29 during pre-monsoon season and 6.56 to 7.04 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 448 to 5402 μS/cm during pre-monsoon season and 425 to 2992 μS/cm during post-monsoon season with almost all the samples having conductivity value above 1000 μS/cm during both pre- and post-monsoon seasons. The maximum conductivity value of 5402 μS/cm was observed at Vatva during pre-monsoon season.

In the present study the values of total dissolved solids (TDS) in the ground water varies from 287 to 3457 mg/L during pre-monsoon season and 272 to 1915 mg/L during post-monsoon season. About 88% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L while about 4% of the samples even exceed the maximum permissible limit of 2000 mg/L (Table 5.1.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water of metropolitan city of Ahmedabad varies from 158 to 610 mg/L during pre-monsoon season and 140 to 536 mg/L during post-monsoon season. Only one sample exceeds the maximum permissible limit of 600 mg/L during pre-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.3(a&b).

Hardness of water is due to carbonates, sulphates and chlorides of calcium and magnesium. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 104 to 1375 mg/L during pre-monsoon season and 79 to 865 mg/L during post-monsoon season. About 48% of the samples of the metropolitan city of Ahmedabad fall within the desirable limit of 300 mg/L while 48% sample also crosses the desirable limit but are well within the permissible limit of 600 mg/L and only 4% sample even crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.1.7). During the post-monsoon season 60% of the samples fall within desirable limit of 300 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.4(a&b).

In ground water of the metropolitan city of Ahmedabad, the values of calcium range from 17 to 284 during pre-monsoon season and 12 to 152 mg/L during post-monsoon season. The values of magnesium vary from 15 to 262 mg/L during pre-monsoon season and 11 to 118 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.5(a&b) and 5.1.6(a&b) respectively.

The concentration of sodium in the metropolitan city varies from 34 to 552 mg/L during pre-monsoon season and 48 to 288 mg/L during post-monsoon season. The Bureau of Indian Standards has not included sodium in drinking water standards. The high sodium values in the study area may be attributed to base-exchange phenomena and causes sodium hazard. Ground water with such high sodium is not suitable for irrigation purpose.

Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. The concentration of potassium in ground water of the study area varies from 2.1 to 8.2 mg/L during pre-monsoon season and 0.4 to 7.9 mg/L during post-monsoon season. The Bureau of Indian Standards has not included potassium in drinking water standards. However, the European Economic Community has prescribed guideline level of potassium at 10 mg/L in drinking water. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre-monsoon season. Almost similar trend was observed during post-monsoon season.

The concentration of chloride varies from 8 to 725 mg/L during pre-monsoon season and 12 to 456 mg/L during post-monsoon season. More than 88% samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.1.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit and 1000 mg/L as the permissible limit for drinking water (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.7(a&b).

The concentration of sulphate in the metropolitan city varies from 9 to 590 mg/L during pre-monsoon season and 10 to 325 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 84% of the samples analysed fall within the desirable limit of 200 mg/L while 12% of the samples exceed the desirable limit but are within the permissible limit of 400 mg/L and only one sample even exceed the maximum permissible limit of 400 mg/L during pre-monsoon season (Table 5.1.11). Almost similar trend was observed during post-monsoon season. The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.8(a&b).

Nitrate content in drinking water is considered important for its adverse health effects and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases. The nitrate content in the metropolitan city of Ahmedabad varies from 0.2 to 610 mg/L during pre-monsoon season and 1.2 to 215 mg/L during post-monsoon season. About 52% of the samples of the metropolitan city of Ahmedabad fall within the desirable limit of 45 mg/L while 16% samples also cross the desirable limit but are well within the permissible limit of

100 mg/L and 32% samples even crosses the permissible limit of 100 mg/L during pre-monsoon season. About 88% of the samples fall within the desirable limit during post-monsoon season (Table 5.1.12). The higher nitrate concentration may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.9(a&b).

The concentration of phosphate in the metropolitan city of Ahmedabad is generally very low at all the locations. Phosphate has a tendency to get adsorbed in the soils, as a result the concentration of phosphate in ground water is usually low.

The presence of fluoride in ground water may be attributed to the localized effects of natural sources. The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water. The fluoride content in the ground water of the study area varies from 0.0 to 1.19 mg/L during pre-monsoon season and 0.1 to 1.57 mg/L during post-monsoon season. More than 60% samples of the metropolitan city falls within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season. No sample exceeds the maximum permissible limit of 1.5 mg/L in pre-monsoon season and only two samples exceeds in post-monsoon (Table 5.1.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.1.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Ahmedabad, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in almost all the samples. The alkalinity values also exceed the desirable limit in more than 88% of the samples in both the seasons. From the hardness point of view, 48% of the samples are within desirable limit during pre-monsoon season, 48% samples also exceed the desirable limit but are within permissible limit and 4% samples even exceeds the maximum permissible limit. The chloride, sulphate and fluoride contents are within the desirable limits in about more than 80% of the samples. The concentration of nitrate is well within the desirable limit in 52% of the samples and 32% exceeds the maximum permissible limit in pre-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Ahmedabad shows bacterial contamination in only two ground water samples during both pre- and post-monsoon seasons.

# Heavy Metals

Heavy metals in ground water have a considerable significance due to their toxicity and adsorption behaviour. Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. Despite the presence of trace concentrations of Cr, Mn, Co, Cu and Zn in the aquatic environment, which is essential to a number of life processes, high concentrations of these metals become toxic. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Ahmedabad are given in Tables 5.1.15 and 5.1.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.1.17 to 5.1.26 and graphically shown in Fig. 5.1.11 to 5.1.18. The toxic effects of these elements and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Ahmedabad ranges from 309 to 3685 μg/L during pre-monsoon season (Table 5.1.15) and 10 to 2870 μg/L during post-monsoon season (Table 5.1.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.1.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is evident from the results that all the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 60% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 56% of the samples falls within the desirable limit and 20% of the samples even exceed the maximum permissible limit (Table 5.1.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata.

It is a known fact that iron in trace amounts is essential for nutrition. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity. The objection to iron in the distribution system is not due to health reason but to staining of laundry and plumbing fixtures and appearance. Taste and order problems may be caused by filamentous organism that prey on iron compounds (frenothrix, gallionella and leptothrix are called iron bacteria), originating another consumer's objection (red water). The presence of iron bacteria may clog well screens or develop in the distribution system, particularly when sulphate compounds in addition to iron may be subjected to chemical reduction.

**Manganese (Mn):** The concentration of manganese ranges from 9 to 134 μg/L during pre-monsoon season (Table 5.1.15) and 3 to 252 μg/L during post-monsoon season (Table 5.1.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.1.12. Manganese is an essential trace nutrient for plants and animals, which does not occur naturally as a metal but is found in various salts and minerals frequently in association with iron compounds. Manganese may gain entry into the body by inhalation, consumption of food and through drinking water. In general concentration of manganese in ground water is less than that of iron. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is evident from the results that about 96% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L. No sample exceeds the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.1.18). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 8 to 227 μg/L during pre-monsoon season (Table 5.1.15) and 2 to 40 μg/L during post-monsoon season during post-monsoon season (Table 5.1.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.1.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Ahmedabad, more than 92% of the samples fall below the desirable limit of 50 μg/L and remaining about 10% samples exceed the desirable limit but are within the maximum permissible limit (Table 5.1.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies.

In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control. Industrial sources can be listed for smelting and refining, copper wire mills, coal burning industries, electroplating, tanning, engraving, photography, insecticides, fungicides, coal burning industries, and iron and steel producing industries. The toxicity of copper to aquatic life is dependent on the alkalinity of the water. At lower alkalinity, copper is generally more toxic to aquatic life. Copper if present in excess amount in public water supplies enhances corrosion of aluminium and zinc utensils and fittings. High intake of copper may results in damage to liver.

**Chromium (Cr):** The concentration of chromium ranges from 3 to 46 μg/L during pre-monsoon season (Table 5.1.15) and 1 to 110 μg/L during post-monsoon season (Table 5.1.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.1.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Ahmedabad, almost all the samples fall well within the desirable limit for drinking water.

Found in the earth's crust, chromium is a naturally occurring metal in drinking water. The two important oxidation states of chromium in natural waters are +3 and +6. Inter-conversions of Cr(+3) and Cr(+6) occur in conditions similar to natural waters. Trivalent chromium may be nutritionally essential with a safe and relative innocuous level. Hexavalent chromium has a deleterious effect on the liver, kidney, and respiratory organs with hemorrhagic effects, dermatitis, and ulceration of the skin for chronic and subchronic exposure. Municipal wastewater release considerable amount of chromium into the environment. In the natural environment, Cr(+6) is likely to be reduced to Cr(+3), thereby reducing the toxic impact of chromium discharges. The pathways of chromium contribution to ground water are that the chromium containing industrial effluent discharged into stream, the hexavalent state chromium may be reduced to trivalent state and later adsorbed on the suspended particlaute. In case, it could not be adsorbed, the chromium remain in the form of colloidal suspension, may precipitate and become part of stream sediment, from where it may reach to ground water through percolation containing shallow aquifers.

**Lead (Pb):** In the study area, the concentration of lead ranges from 4 to 57 μg/L during pre-monsoon season (Table 5.1.15) and 4 to 45 μg/L during post-monsoon season (Table 5.1.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.1.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Ahmedabad, almost all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons and is safe for drinking purpose.

Lead is not considered an essential nutritional element and is a cumulative poison to humans. Acute lead poisoning is extremely rare. The typical symptoms of advanced lead poisoning are constipation, anemia, gastrointestinal disturbance, tenderness and gradual paralysis in muscles, specifically arms with possible cases of lethargy and moroseness. The major source of lead contamination is the combustion of fossil fuel. Lead is removed from the atmosphere by rain and falls back on the earth surface and seeps into the ground. Lead passes from the soil to water and to the plants and finally into the food chain. In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. It may be noted that the use of soft water of slightly acidic pH and the use of lead pipes in service and domestic water lines may provide higher concentrations of lead at the consumers's tap, particularly when the water use is minimal in the household (overnight still water in pipes).

**Cadmium (Cd):** The cadmium content in the study area varies from 2 to 12 μg/L during pre-monsoon season (Table 5.1.15) and 1 to 15 μg/L during post-monsoon season (Table 5.1.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.1.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Ahmedabad, about 88% of the samples are found within the permissible limit during both pre- and post-monsoon seasons (Table 5.1.23). The drinking water having more than 10 μg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals.

Cadmium is found in low concentrations in rocks, coal, and petroleum, it is found in ground water more than in surface water as a natural occurrence. Therefore it may enter the water supply from variety of industrial applications including mining and smelting, electroplating, and pigment and plasticizer production, and leachates from landfills. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 240 to 5330 μg/L during pre-monsoon season (Table 5.1.15) and 12 to 4330 μg/L during post-monsoon season (Table 5.1.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.1.18. The Bureau of Indian Standards has prescribed

5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Ahmedabad, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

The presence of zinc can be detected only in traces in natural water. USEPA has not identified any adverse effects that are caused by zinc and has not proposed primary or secondary standards. It is an extremely remote possibility that detrimental health effects may be generated by zinc in drinking water, on the other hand, there is a concern of borderline deficiencies in children nutrition. A higher concentration of zinc (>15 mg/L) is aesthetically objectionable in drinking water due to a milky appearance and a greasy film in boiling.

**Arsenic (As):** The concentration of arsenic in the study area ranges from ND to 30 μg/L during pre-monsoon season (Table 5.1.15) and ND to 16 μg/L during post-monsoon season (Table 5.1.16). Ground water is expected to contain higher arsenic concentrations than surface water. Because of its presence in geological materials, arsenic can be traced in water as originated by natural processes or by industrial activities – industrial waste, arsenical pesticides and smelting operations. Generally, arsenic found in two state – As(+3) and As(+5) in ground water. As(+3) compounds are more toxic than As(+6) compounds. Arsenic compounds are skin and lung carcinogens in humans. The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found within the limit prescribed by BIS (1991).

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 30 μg/L during pre-monsoon season (Table 5.1.15) and ND to 16 μg/L during post-monsoon season (Table 5.1.16). Mercury in natural waters can exist in three oxidation states: elemental mercury (0), the mercurous (+1) state and the mercuric (+2) state. The nature of the species and their distribution will depend upon the pH, redox potential, and nature and concentrations of anions which form stable complexes with mercury. In well-aerated water (Eh≥0.5 V) mercuric species will predominate whereas, under reducing conditions, elemental mercury should prevail. Presence of enough sulfide ion stabilizes bivalent mercury as hydrosulfide or sulfide complexes, even at very low redox potentials. Mercury forms a group of compounds called organic mercurials (e.g. Methylmercury). Mercurials have found widespread use in insecticides, fungicides, bactericides, pharmaceuticals and in manufactures of synthetic polymers. The principal target organ of inorganic mercury is the kidneys, with neurological and renal disturbances. Methyl mercury compounds are very toxic to the central nervous system; they are also the major source of environmental contamination. The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, all the samples were found within the limit prescribed by BIS (1991) both in pre- and post-monsoon seasons.

It is inferred from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron in 60% samples, nickel in 96% samples, cadmium in 12% samples during pre-monsoon season.

# Pesticides

Pesticides in general are the substances mainly chemical in nature that are used to kill or control the unwanted species such as insects, fungi, weeds, rodents, mites, nematodes etc. However, the chemical pesticides are usually not target specific and therefore, may cause harm to non-target species and many of them are quite persistent for long periods in the environment. Presently, synthetic organic pesticides, viz., organo-chlorinated and organic phosphorous compounds are largely used to control insects and other pests. The indiscriminate application of pesticides provides the pollutional effect to a considerable extent. The pesticides join the water courses through the runoff from agricultural lands, industrial and urban effluents, spray operations for crop and disease vector control etc and may ultimately reach to the ground water through percolation. The pesticides may impart toxicity to the ground water and causes various health hazards.

During present course of investigaton of the metropolitan city of Ahmedabad, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.1.27 and 5.1.28. Out of the seven chlorinated pesticides analysed, only two pesticides (Aldrin, and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at few locations. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Ahmedabad, no PAH was detected.

# 5.15.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Ahmedabad are given in Table 5.1.29.

## Salinity

The electrical conductivity values in the metropolitan city of Ahmedabad varies widely from 448 to 5402 μS/cm during pre-monsoon season and 425 to 2992 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 1.25 to 9.61 during pre-monsoon season and 1.52 to 6.80 during post-monsoon season. The sodium percentage in the study area was found to vary from 34.8 to 75.5% during pre-monsoon season and 30.4 to 67.9 during post-monsoon season. Only five samples of the study area exceed the recommended value of percentage of sodium of 60% during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is susceptible to residual sodium carbonate hazard at many locations.

## Boron

In the present investigation of metropolitan city of Ahmedabad, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.15.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.1.30 and 5.1.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Ahmedabad have been plotted on trilinear diagram for both the surveys (Fig. 5.1.19 and 5.1.20) and results have been summarized in Table 5.1.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-$HCO_3$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to Ca-Mg-

$Cl-SO_4$ or $Na-K-Cl-SO_4$ hydrochemical facies.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Ahmedabad have been plotted on Chadha' diagram (Fig. 5.1.21 and 5.1.22) and results have been summarized in Table 5.1.30. It is evident from the results that majority of the samples of the metropolitan city belong to Group 8 ($Na-K-HCO_3$) or Group 5 ($Ca-Mg-HCO_3$) hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to Group 6 ($Ca-Mg-Cl-SO_4$) or Group 7 ($Na-K-Cl-SO_4$) hydrochemical facies.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.1.23 and 5.1.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to $Na-K-HCO_3$ or $Ca-Mg-HCO_3$ hydrochemical facies in both pre- and post-monsoon season. Few samples of the metropolitan city also belong to $Ca-Mg-Cl-SO_4$ or $Na-K-Cl-SO_4$ hydrochemical facies.

## U.S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Ahmedabad has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.1.25 and 5.1.26) and the results have been summarized in Table 5.1.30. It is inferred from the results that the majority of ground water samples of the metropolitan city of Ahmedabad falls under water types C3-S1 followed by C3-S2, C2-S1 and C4-S2. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. C4-S2 type water (very high salinity and medium SAR) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Ahmedabad has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.1.31**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.16 Rajkot

## 5.16.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Rajkot were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources. The location of sampling sites is shown in Fig. 5.2.1. The details of sampling locations and source and depth wise distribution are given in Table 5.2.1 and 5.2.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.2.3 and 5.2.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.2.5 to 5.2.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.2.2 to 5.2.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Rajkot mostly fall within the range 6.56 to 9.94 during pre-monsoon season and 6.42 to 7.49 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 866 to 2975 μS/cm during pre-monsoon season and 840 to 2452 μS/cm during post-monsoon season with almost all the samples having conductivity value above 1000 μS/cm during both pre- and post-monsoon seasons. The maximum conductivity value of 2975 μS/cm was observed in the sample of District Jail during pre-monsoon season.

In the metropolitan city of Rajkot, the values of total dissolved solids (TDS) in the ground water varies from 554 to 1904 mg/L during pre-monsoon season and 538 to 1569 mg/L during post-monsoon season. All samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L (Table 5.2.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). In metropolitan city of Rajkot, Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. The alkalinity value in the ground water of metropolitan city of Rajkot varies from 138 to 486 mg/L during pre-monsoon season and 118 to 332 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre-and post-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 302 to 1155 mg/L during pre-monsoon season and 244 to 963 mg/L during post-monsoon season. About 68% of the samples of the metropolitan city of Rajkot crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 32% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.2.7). During the post-monsoon season 8% of the samples fall within desirable limit of 300 mg/L and 28% sample crosses the permissible limit of 600 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.4(a&b).

In ground water of the metropolitan city of Rajkot, the values of calcium range from 48 to 306 mg/L during pre-monsoon season and 48 to 276 mg/L during post-monsoon season. The values of magnesium vary from 14 to 116 mg/L during pre-monsoon season and 12 to 110 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, only few samples exceed the maximum permissible limit of calcium and magnesium as 200 mg/L and 75 mg/L. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.5(a&b) and 5.2.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Rajkot varies from 39 to 225 mg/L during pre-monsoon season and 45 to 185 mg/L during post-monsoon season. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena causing sodium hazards. Ground water with high value of sodium is not suitable for irrigation purpose.

The concentration of potassium in ground water of the study area varies from 1.3 to 8.2 mg/L during pre-monsoon season and 0.3 to 1.6 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season. Almost similar trend was observed during post-monsoon season.

The concentration of chloride varies from 99 to 865 mg/L during pre-monsoon season and 72 to 620 mg/L during post-monsoon season. More than 68% samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.2.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The concentration of sulphate in the metropolitan city varies from 25 to 236 mg/L during pre-monsoon season and 22 to 230 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 96% of the samples analysed fall within the desirable limit of 200 mg/L while 4% of the samples exceed the desirable limit but are within the permissible limit of 400 mg/L and no sample exceeds the maximum permissible limit of 400 mg/L during pre-monsoon season (Table 5.2.11). Almost similar trend was observed during post-monsoon season. The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.8(a&b).

The nitrate content in the metropolitan city of Rajkot varies from 9.4 to 225 mg/L during pre-monsoon season and 4.4 to 182 mg/L during post-monsoon season. About 56% of the samples of the metropolitan city of Rajkot fall within the permissible limit of 100 mg/L and 44% of samples even cross the permissible limit of 100 mg/L during pre-monsoon season. About 72% of the samples fall within the permissible limit and 28% of samples cross the permissible limit during post-monsoon season (Table 5.2.12). In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases. The higher nitrate concentration in the metropolitan city of Rajkot may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.9(a&b).

The concentration of phosphate in the metropolitan city of Rajkot is generally very low except at few locations. The concentration of phosphate at few location may be attributed to various chemical processes in soil strata that may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the study area varies from 0.0 to 0.36 mg/L during pre-monsoon season and 0.10 to 0.70 mg/L during post-monsoon season. All the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.2.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.2.10(a&b).

From the above discussion, it is revealed that in the metropolitan city of Rajkot, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in all the samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in more than 80% of the samples in pre-monsoon season. From the hardness point of view, all the samples exceed the desirable limit and about 68% of the samples are within permissible limit and 32% samples even exceeds the permissible limit during pre-monsoon season. The chloride and sulphate contents are within the desirable limits in about more than 70% of the samples. The nitrate content in about 56% samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

## Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Rajkot shows bacterial contamination in only three ground water samples during pre-monsoon season but within the permissible limit.

## Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Rajkot are given in Tables 5.2.15 and 5.2.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.2.17 to 5.2.26 and graphically shown in Fig. 5.2.11 to 5.2.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Rajkot ranges from 223 to 4452 μg/L during pre-monsoon season (Table 5.2.15) and 45 to 5769 μg/L during post-monsoon season (Table 5.2.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.2.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is evident from the results that 82% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 44% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 16% of the samples fall within the desirable limit and 56% of the samples even exceed the maximum permissible limit (Table 5.2.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

**Manganese (Mn):** The concentration of manganese ranges from 14 to 643 μg/L during pre-monsoon season (Table 5.2.15) and 7 to 183 μg/L during post-monsoon season (Table 5.2.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.2.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is evident from the results that about 80% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L. No sample exceeds the maximum permissible limit of 300 μg/L during both pre-and post-monsoon seasons (Table 5.2.18).

**Copper (Cu):** The concentration of copper ranges from 3 to 76 μg/L during pre-monsoon season (Table 5.2.15) and 2 to 42 μg/L during post-monsoon season during post-monsoon season (Table 5.2.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.2.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Rajkot, more than 92% of the samples fall below the desirable limit of 50 μg/L and remaining about 8% samples exceed the desirable limit but are within the maximum permissible limit (Table 5.2.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control.

**Chromium (Cr):** The concentration of chromium ranges from 1 to 73 μg/L during pre-monsoon season (Table 5.2.15) and 1 to 153 μg/L during post-monsoon season (Table 5.2.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.2.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Rajkot, almost all the samples fall well within the desirable limit for drinking water.

**Lead (Pb):** In the study area, the concentration of lead ranges from 5 to 67 μg/L during pre-monsoon season (Table 5.2.15) and 21 to 73 μg/L during post-monsoon season (Table 5.2.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.2.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Rajkot, almost all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons and is safe for drinking purpose.

**Cadmium (Cd):** The cadmium content in the study area varies from 3 to 13 μg/L during pre-monsoon season (Table 5.2.15) and 5 to 9 μg/L during post-monsoon season (Table 5.2.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.2.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Rajkot, almost all the samples fall within the permissible limit during both pre- and post-monsoon seasons (Table 5.2.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 340 to 5250 μg/L during pre-monsoon season (Table 5.2.15) and 19 to 4627 μg/L during post-monsoon season (Table 5.2.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.2.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Rajkot, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996). The presence of zinc can be detected only in traces in natural water. USEPA has not identified any adverse effects that are caused by zinc and has not proposed primary or secondary standards.

**Arsenic (As):** The concentration of arsenic in the study area is not detected during both pre- and post-monsoon seasons (Table 5.2.15 & Table 5.2.16). The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found free from arsenic contamination.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 1.0 μg/L during pre-monsoon season (Table 5.2.15) and is not detected during post-monsoon season (Table 5.2.16). The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, all the samples were found within the limit prescribed by BIS (1991) both in pre- and post-monsoon seasons.

It is inferred from the above discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (44% samples), nickel (all samples) and lead (12% samples) during pre-monsoon season.

## Pesticides

During present survey of ground water quality of the metropolitan city of Rajkot, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.2.27 and 5.2.28. Out of the seven chlorinated pesticides analysed, only three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of almost all the pesticides were within the permissible limits except at few locations. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Rajkot, no PAH was detected.

## 5.16.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Rajkot are given in Table 5.2.29.

## Salinity

The electrical conductivity values in the metropolitan city of Rajkot varies widely from 866 to 2975 μS/cm during pre-monsoon season and 840 to 2452 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from

0.87 to 3.03 during pre-monsoon season and 0.75 to 2.99 during post-monsoon season. The sodium percentage in the study area was found to vary from 17.7 to 42.2% during pre-monsoon season and 10.9 to 40.2 during post-monsoon season. None of sample exceeds the recommended value of percentage of sodium of 60% for irrigation during both pre- and post-monsoon seasons and is suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Rajkot, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.16.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.2.30 and 5.2.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Rajkot have been plotted on trilinear diagram for both the surveys (Fig. 5.2.19 and 5.2.20) and results have been summarized in Table 5.2.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon seasons.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Rajkot have been plotted on Chadha' diagram (Fig. 5.2.21 and 5.2.22) and results have been summarized in Table 5.2.30. It is evident from the results that majority of the samples of the metropolitan city belong to Group 6 (Ca-Mg-Cl-$SO_4$) or Group 5 (Ca-Mg-$HCO_3$) hydrochemical facies in both pre- and post-monsoon seasons.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.2.23 and 5.2.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Rajkot has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.2.25 and 5.2.26) and the results have been summarized in Table 5.2.30. It is evident from the results that the majority of ground water samples of the metropolitan city of Rajkot falls under water types C3-S1 followed by C4-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. C4-S1 type water (very high salinity and low SAR) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Rajkot has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.2.31**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to medium alkalinity water as per alkalinity classification**.**

# 5.17 Surat

## 5.17.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Surat were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources. The location of sampling sites is shown in Fig. 5.3.1. The details of sampling locations and source and depth wise distribution are given in Table 5.3.1 and 5.3.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.3.3 and 5.3.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.3.5 to 5.3.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.3.2 to 5.3.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Surat mostly fall within the range 6.46 to 7.91 during pre-monsoon season and 6.43 to 7.65 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 540 to 12388 μS/cm during pre-monsoon season and 524 to 11268 μS/cm during post-monsoon season with almost 76% of the samples having conductivity value above 1000 μS/cm during both pre- and post-monsoon seasons. The maximum conductivity value of 12388 μS/cm was observed in the sample of Atwa Gate during pre-monsoon season.

In the metropolitan city of Surat, the values of total dissolved solids (TDS) in the ground water varies from 346 to 7928 mg/L during pre-monsoon season and 335 to 7212 mg/L during post-monsoon season. About 44% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during pre-monsoon and 32% samples found to exceed the mximum permissible limit in pre-monsoon season (Table 5.3.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). The high values of TDS at some locations may be attributed to the high mineralization in the ground water of the study area. The ground water at these locations indicated very high salinity due to which it is not suitable even for agriculrure purposes.Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. The alkalinity value in the ground water of metropolitan city of Surat varies from 152 to 805 mg/L during pre-monsoon season and 144 to 446 mg/L during post-monsoon season. Only two samples exceed the maximum permissible limit of 600 mg/L during pre- monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 177 to 1229 mg/L during pre-monsoon season and 153 to 1300 mg/L during post-monsoon season. About 36% of the samples of the metropolitan city of Surat crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 32% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.3.7). During the post-monsoon season 44% of the samples fall within desirable limit of 300 mg/L and 16% sample crosses the permissible limit of 600 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.4(a&b).

In ground water of the metropolitan city of Surat, the values of calcium range from 14 to 186 mg/L during pre-monsoon season and 12 to 202 mg/L during post-monsoon season. The values of magnesium vary from 25 to 186 mg/L during pre-monsoon season and 25 to 208 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). No sample exceeds the maximum permissible limit of calcium as 200 mg/L. During pre monsoon 56% samples exceed the maximum permissible limit of magnesium as 75 mg/L. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.5(a&b) and 5.3.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Surat varies from 26 to 2530 mg/L during pre-monsoon season and 18 to 2242 mg/L during post-monsoon season. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena causing sodium hazards. Ground water with high value of sodium is not suitable for irrigation purpose.

The concentration of potassium in ground water of the study area varies from 0.1 to 6.1 mg/L during pre-monsoon season and 0.4 to 33 mg/L during post-monsoon season. As per EEC criteria, only two samples exceeds the guideline level of 10 mg/L during post-monsoon season and no sample exceeds the level during pre-monsoon season.

The concentration of chloride varies from 25 to 4085 mg/L during pre-monsoon season and 48 to 3622 mg/L during post-monsoon season. More than 44% samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.3.10). Four sample of the city exceeds the maximum permissible limit of 1000 mg/L during pre-monsoon and two during post-monsoon season. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.7(a&b).

The concentration of sulphate in the metropolitan city varies from 7 to 540 mg/L during pre-monsoon season and 1 to 600 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 84% of the samples analysed fall within the desirable limit of 200 mg/L while 12% of the samples exceed the desirable limit but are within the permissible limit of 400 mg/L and only one sample exceeds the maximum permissible limit of 400 mg/L during pre-monsoon season (Table 5.3.11). Almost similar trend was observed during post-monsoon season. The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.8(a&b).

The nitrate content in the metropolitan city of Surat varies from 0.3 to 180 mg/L during pre-monsoon season and 4.4 to 99 mg/L during post-monsoon season. About 88% of the samples of the metropolitan city of Surat fall within the desirable limit of 45 mg/L and 8% of samples even cross the permissible limit of 100 mg/L during pre-monsoon season. About 60% of the samples fall within the desirable limit and 40% of samples cross the permissible limit during post-monsoon season (Table 5.3.12). In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases. The higher nitrate concentration may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.9(a&b).

The concentration of phosphate in the metropolitan city of Surat is generally very low except at few locations, which may be attributed to various processes in soil strata that may induce the mobility of phosphate in sub-soil and ground water

The fluoride content in the ground water of the study area varies from 0.34 to1.37 mg/L during pre-monsoon season and 0.2 to 1.28 mg/L during post-monsoon season. 96% samples of the metropolitan city falls within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.3.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.3.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Surat, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 76% of the samples.The alkalinity values also exceed the desirable limit in more than 68% of the samples in both the seasons. From the hardness point of view, about 32% of the samples exceed the desirable limit and about 68% of the samples are within permissible limit and 32% samples even exceeds the permissible limit during pre-monsoon season. The magnesium content exceeds the maximum permissible limit in 56% of the samples in pre-monsoon season. The chloride content exceeds the desirable limit in more than 56% of the pre-monsoon samples. The sulphate content is within the desirable limits in about more than 84% of the samples. The nitrate content in more than 88% samples is well within the desirable limit in pre-monsoon season. The concentration of fluoride is well within the desirable limit in all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Surat shows bacterial contamination in only five ground water samples during pre-monsoon season but within the permissible limit.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Surat are given in Tables 5.3.15 and 5.3.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.3.17 to 5.3.26 and graphically shown in Fig. 5.3.11 to 5.3.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Surat ranges from 172 to 2998 μg/L during pre-monsoon season (Table 5.3.15) and 101 to 2917 μg/L during post-monsoon season (Table 5.3.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.3.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is evident from the results that 84% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 48% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 76% of the samples exceed the desirable limit and 40% of the samples even exceed the maximum permissible limit (Table 5.3.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

**Manganese (Mn):** The concentration of manganese in the ground water of the metropolitan city of Surat ranges from 7 to 734 μg/L during pre-monsoon season (Table 5.3.15) and 9 to 486 μg/L during post-monsoon season (Table 5.3.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.3.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is evident from the results that about 60% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 16% of the samples exceed the maximum permissible limit of 300 μg/L in pre-monsoon season (Table 5.3.18). High concentration of manganese at few locations may be attributed to reducing condition of water and thereby the dissolution of manganese bearing minerals from the soil strata of the study area. The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper in the ground water of the metropolitan city of Surat ranges from 5 to 44 μg/L during pre-monsoon season (Table 5.3.15) and 2 to 68 μg/L during post-monsoon season (Table 5.3.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.3.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). In the metropolitan city of Surat, almost all the samples fall well within the desirable limit for drinking water in both pre- and post-monsoon seasons.

**Chromium (Cr):** The concentration of chromium in the ground water of the metropolitan city of Surat ranges from 2 to 30 μg/L during pre-monsoon season (Table 5.3.15) and 2 to 38 μg/L during post-monsoon season (Table 5.3.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.3.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Surat, all the samples fall well within the desirable limit for drinking water in both pre- and post-monsoon seasons.

**Lead (Pb):** The concentration of lead in the ground water of the metropolitan city of Surat ranges from 5 to 177 μg/L during pre-monsoon season (Table 5.3.15) and 10 to 2690 μg/L during post-monsoon season (Table 5.3.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.3.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Surat, 84% of the samples fall within the permissible limit during pre-monsoon season and 76% of the samples falls within permissible limit during the post-monsoon season. About 16% and 24% of the samples crosses the permissible limit during pre- and post-monsoon seasons respectively and not safe for drinking water (Table 5.3.22). In the study area, higher value of lead may be attributed to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** The cadmium content in the study area varies from 2 to 25 µg/L during pre-monsoon season (Table 5.3.15) and 2 to 9 µg/L during post-monsoon season (Table 5.3.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.3.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Surat, about 68% of the samples are found within the permissible limit and 32% of the samples exceed the permissible limit during pre-monsoon season and all samples are found within the permissible limit during post-monsoon season (Table 5.3.23). The drinking water having more than 10 µg/L of cadmium can cause bronchitis, emphysema, anaemia and renal stone formation in animals. The high values of cadmium in the study area may be attributed to industrial discharges and leaches from land filled areas.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 230 to 3625 µg/L during pre-monsoon season (Table 5.3.15) and 47 to 2667 µg/L during post-monsoon season (Table 5.3.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.3.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Surat, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

**Arsenic (As):** The concentration of arsenic in the study area is not detected during both pre- and post-monsoon seasons (Table 5.3.15 & Table 5.3.16). The Bureau of Indian Standards has prescribed 50 µg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 µg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found from arsenic contamination.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 3.0 µg/L during pre-monsoon season (Table 5.3.15) and is not detected during post-monsoon season (Table 5.3.16). The Bureau of Indian Standards has prescribed 1 µg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 µg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, only two samples were found having concentration of mercury beyond the limit prescribed by BIS (1991) in pre-monsoon season.

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (48% samples), nickel (76% samples), lead (16% samples) and cadmium (32% samples) during pre-monsoon season.

# Pesticides

During present investigation of ground water quality of the metropolitan city of Surat, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.3.27 and 5.3.28. Out of the seven chlorinated pesticides analysed, only three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at two locations. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Surat, no PAH was detected.

## 5.17.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Surat are given in Table 5.3.29.

## Salinity

The electrical conductivity value in the metropolitan city of Surat varies widely from 540 to 12388 μS/cm during pre-monsoon season and 524 to 11268 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.74 to 31.40 during pre-monsoon season and 0.34 to 27.12 during post-monsoon season. The sodium percentage in the study area was found to vary from 19.9 to 88.9 during pre-monsoon season and 8.4 to 79.1 during post-monsoon season. Seven samples of the study area exceed the recommended value of percentage of sodium of 60% for irrigation during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard except at few locations.

## Boron

In the present investigation of metropolitan city of Surat, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.17.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.3.30 and 5.3.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Surat have been plotted on trilinear diagram for both the surveys (Fig. 5.3.19 and 5.3.20) and results have been summarized in Table 5.3.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Surat have been plotted on Chadha' diagram (Fig. 5.3.21 and 5.3.22) and results have been summarized in Table 5.3.30. It is evident from the results that majority of the samples of the metropolitan city belong to Group 7 (Na-K-Cl- $SO_4$) or Group 5 (Ca-Mg- $HCO_3$ ) hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.3.23 and 5.3.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Na-K-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Surat has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.3.25 and 5.3.26) and the results have been summarized in Table 5.3.30. It is evident from the results that the majority of ground water samples of the metropolitan city of Surat falls under water types C3-S2 followed by C3-S1 and C2-S1. The C3-S1 type water (high salinity and medium SAR) cannot be used on soils with restricted drainage and may be used on coarse-textural or organic soils with good permeability. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. C2-S1 type water (medium salinity and low SAR) is suitable for plants with moderate salt tolerance without special practices for salinity control.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Surat has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.3.31**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to medium saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.18 Vadodara

## 5.18.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Vadodara were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.4.1. The details of sampling locations and source and depth wise distribution are given in Table 5.4.1 and 5.4.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.4.3 and 5.4.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.4.5 to 5.4.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.4.2 to 5.4.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Vadodara mostly fall within the range 7.5 to 8.63 during pre-monsoon season and 6.61 to 7.74 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 552 to 4920 μS/cm during pre-monsoon season and 498 to 3615 μS/cm during post-monsoon season with almost 88% of the samples having conductivity value above 1000 μS/cm during pre-monsoon seasons. The maximum conductivity value of 4920 μS/cm was observed in the sample of Harni during pre-monsoon season.

In the metropolitan city of Vadodara, the values of total dissolved solids (TDS) in the ground water varies from 353 to 3149 mg/L during pre-monsoon season and 319 to 2314 mg/L during post-monsoon season. About 88% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L during pre-monsoon and only 8% of the samples exceed the maximum permissible limit in pre-monsoon season (Table 5.4.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. The alkalinity value in the ground water of metropolitan city of Vadodara varies from 162 to 780 mg/L during pre-monsoon season and 126 to 604 mg/L during post-monsoon season. Only two samples exceed the maximum permissible limit of 600 mg/L during pre- and post-monsoon seasons. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 112 to 1187 mg/L during pre-monsoon season and 161 to 782 mg/L during post-monsoon season. About 68% of the samples of the metropolitan city of Vadodara crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 12% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.4.7). During the post-monsoon season 36% of the samples fall within desirable limit of 300 mg/L and 12% sample crosses the permissible limit of 600 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.4(a&b).

In ground water of the metropolitan city of Vadodara, the values of calcium range from 25 to 212 mg/L during pre-monsoon season and 26 to 165 mg/L during post-monsoon season. The values of magnesium vary from 8 to 160 mg/L during pre-monsoon season and 10 to 92 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, only few samples exceed maximum permissible limit of calcium as 200 mg/L and magnesium as 75 mg/L during pre monsoon. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.5(a&b) and 5.4.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Vadodara varies from 36 to 560 mg/L during pre-monsoon season and 32 to 453 mg/L during post-monsoon season. The high sodium values in the metropolitan city may be attributed to base-exchange phenomena causing sodium hazards. Such ground water with high value of sodium is not suitable for irrigation purpose.

The concentration of potassium in ground water of the study area varies from

1.7 to 13 mg/L during pre-monsoon season and 0.2 to 23 mg/L during post-monsoon season. As per EEC criteria, only one sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon seasons.

The concentration of chloride varies from 36 to 826 mg/L during pre-monsoon season and 38 to 525 mg/L during post-monsoon season. More than 84% samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.4.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L during both pre and post-monsoon season. . The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.7(a&b).

The concentration of sulphate in the metropolitan city varies from 14 to 656 mg/L during pre-monsoon season and 10 to 475 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 96% of the samples analysed fall within the desirable limit of 200 mg/L and only one sample exceeds the maximum permissible limit of 400 mg/L during pre- and post-monsoon seasons (Table 5.4.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.8(a&b).

The nitrate content in the metropolitan city of Vadodara varies from 0.8 to 350 mg/L during pre-monsoon season and 0.4 to 255 mg/L during post-monsoon season. About 84% of the samples of the metropolitan city of Vadodara fall within the permissible limit of 100 mg/L and four samples even cross the permissible limit of 100 mg/L during pre-monsoon season (Table 5.4.12). In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. The higher nitrate concentration in the metropolitan city of Rajkot at few locations may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.9(a&b).

The concentration of phosphate in the metropolitan city of Vadodara is generally very low except at few locations and may be attributed to various chemical processes in soil strata that may induce the mobility of phosphate in sub-soil and ground water

The fluoride content in the ground water of the study area varies from 0.08 to1.38 mg/L during pre-monsoon season and 0.24 to 1.34 mg/L during post-monsoon season. 76% samples of the metropolitan city falls within the desirable limit of 1.0 mg/L during pre-monsoon and 80% during post-monsoon season. No sample exceed the maximum permissible limit during both the pre- and post-monsoon season (Table 5.4.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.4.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Vadodara, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 96% of the samples. The alkalinity values also exceed the desirable limit in more than 96% of the samples in both the seasons. From the hardness point of view, about 80% of the samples exceed the desirable limit and about 12% samples even exceed the permissible limit during pre-monsoon season. The chloride content exceeds the desirable limit in more than 16% of the pre-monsoon samples. Sulphate contents are within the desirable limits in almost all of the samples. The nitrate content in more than 72% samples is well within the desirable limit. The concentration of fluoride in more than 76% samples is well within the desirable limit both in pre-and post-monsoon seasons. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Vadodara shows bacterial contamination in only five ground water samples during pre-monsoon season and in two samples in post-monsoon season but within the permissible limit.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Vadodara are given in Tables 5.4.15 and 5.4.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.4.17 to 5.4.26 and graphically shown in Fig. 5.4.11 to 5.4.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Vadodara ranges from 250 to 5830 μg/L during pre-monsoon season (Table 5.4.15) and 124 to 13690 μg/L during post-monsoon season (Table 5.4.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.4.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). ). Limits of iron in water supplies for potable use have not been laid down from health consideration but due to the fact that iron in water supplies may cause discoloration of clothes, plumbing fixtures and porcelain wares. It is evident from the results that 92% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 80% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 96% of the samples exceed the desirable limit and 76% of the samples even exceed the maximum permissible limit (Table 5.3.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata in the study area. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water. It can also discolour clothes, plumbing fixtures and cause scaling which encrusts pipes. Excessive concentration may promote bacterial activities in pipe and service mains, causing objectionable odours and red-rod disease in water. Well water containing soluble iron remain clear while pumped out, but exposure to air causes precipitation of iron due to oxidation, with a consequence of rusty colour and turbidity.

**Manganese (Mn):** The concentration of manganese in the ground water of the metropolitan city of Vadodara ranges from 6 to 236 μg/L during pre-monsoon season (Table 5.4.15) and 21 to 726 μg/L during post-monsoon season (Table 5.4.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.4.12. The desirable limit of concentration of manganese as 100 μg/L has been recommended and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is inferred from the results that about 72% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and none of the samples exceeds the maximum permissible limit of 300 μg/L in pre-monsoon season (Table 5.4.18).

**Copper (Cu):** The concentration of copper in the ground water of the metropolitan city of Vadodara ranges from 3 to 100 μg/L during pre-monsoon season (Table 5.4.15) and 2 to 140 μg/L during post-monsoon season (Table 5.4.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.4.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limits and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). Beyond 50 μg/L, the water imparts astringent taste and cause discoloration and corrosion of pipes, fittings and utensils. World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Vadodara, more than 88% of the samples fall below the desirable limit of 50 μg/L and remaining about 12% samples exceeds the desirable limit but are within the maximum permissible limit in pre-monsoon season (Table 5.4.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies. Low levels of copper may be attributed to rock weathering. In general the principal sources of copper in water supplies are corrosion of brass and copper pipe and addition of copper salts during water treatment for algae control.

**Chromium (Cr):** The concentration of chromium in the ground water of the metropolitan city of Vadodara ranges from 2 to 48 μg/L during pre-monsoon season (Table 5.4.15) and 2 to 22 μg/L during post-monsoon season (Table 5.4.16) and in this range it is not harmful in drinking water. The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.4.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Vadodara, all the samples fall well within the desirable limit for drinking water.

**Lead (Pb):** The concentration of lead in the ground water of the metropolitan city of Vadodara ranges from 10 to 96 μg/L during pre-monsoon season (Table 5.4.15) and 4 to 126 μg/L during post-monsoon season (Table 5.4.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.4.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Vadodara, 88% of the samples fall within the permissible limit during pre-monsoon season and 80% of the samples falls within permissible limit during the post-monsoon season. Remaining 12% and 20% of the samples crosses the permissible limit during pre- and post-monsoon seasons respectively and not safe for drinking water (Table 5.4.22). In drinking water it occurs primarily due to corrosion of lead pipes and solders, especially in areas of soft water. Since dissolution of lead requires an extended contact time, lead is most likely to be present in tap water after being in the service connection piping and plumbing overnight.

**Cadmium (Cd):** The concentration of cadmium in the ground water of the metropolitan city of Vadodara ranges from 3 to 23 µg/L during pre-monsoon season (Table 5.4.15) and 1 to 20 µg/L during post-monsoon season (Table 5.4.16). Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.4.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Vadodara, almost all the samples of the study area are found within the permissible limit during pre- as well as post-monsoon season (Table 5.4.23).

**Zinc (Zn):** The concentration of cadmium in the ground water of the metropolitan city of Vadodara ranges from 190 to 1960 µg/L during pre-monsoon season (Table 5.4.15) and 8 to 4370 µg/L during post-monsoon season (Table 5.4.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.4.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Vadodara, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

**Arsenic (As):** The concentration of arsenic in the ground water of the study area ranges from ND to 234 µg/L during pre-monsoon season and ND to 78 µg/L in post-monsoon season (Table 5.4.15 & Table 5.4.16). The Bureau of Indian Standards has prescribed 50 µg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 µg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, about 40% of the samples exceed the permissible limit of 50 µg/L in pre-monsoon season. The high concentration of the arsenic observed at few locations may be attributed to industrial activities in the study area.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 2.0 µg/L during pre-monsoon season (Table 5.3.15) and ND to 1.0 µg/L during post-monsoon season (Table 5.3.16). The Bureau of Indian Standards has prescribed 1 µg/L as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 µg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, only one sample was found having concentration of mercury beyond the limit prescribed by BIS (1991) in pre-monsoon season.

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (80% samples), nickel (all samples), lead (12% samples) and arsenic (40% samples) during pre-monsoon season.

# Pesticides

During present ground water quality survey of the metropolitan city of Vadodara, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.4.27 and 5.4.28. Out of the seven chlorinated pesticides analysed, only two pesticides ( DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at few locations. The concentrations of these pesticides were lower in the post-monsoon season as compared to pre-monsoon season. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Vadodara, no PAH was detected.

## 5.18.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Vadodara are given in Table 5.4.29.

## Salinity

The electrical conductivity values in the metropolitan city of Vadodara varies widely from 552 to 4920 μS/cm during pre-monsoon season and 498 to 3615 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 1.21 to 15.18 during pre-monsoon season and 1.10 to 11.51 during post-monsoon season. The sodium percentage in the study area was found to vary from 27.8 to 84.6 during pre-monsoon season and 23.9 to 82.5 during post-monsoon season. Only three samples of the study area exceed the recommended value of percentage of sodium of 60% for irrigation during both pre- and post-monsoon seasons and are not suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at almost all locations.

## Boron

In the present investigation of metropolitan city of Vadodara, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.18.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.4.30 and 5.4.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Vadodara have been plotted on trilinear diagram for both the surveys (Fig. 5.4.19 and 5.4.20) and results have been summarized in Table 5.4.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon seasons.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Vadodara have been plotted on Chadha' diagram (Fig. 5.4.21 and 5.4.22) and results have been summarized in Table 5.4.30. It is evident from the results that majority of the samples of the metropolitan city belong to Group 5 (Ca-Mg- $HCO_3$ ) hydrochemical facies in both pre- and post-monsoon seasons.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.4.23 and 5.4.24 respectively. . It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon seasons.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Vadodara has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.4.25 and 5.4.26) and the results have been summarized in Table 5.4.30. It is evident from the results that the majority of ground water samples of the metropolitan city of Vadodara falls under water types C3-S1 followed by C3-S2. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Vadodara has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.4.31**.** It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.19 Asansol

## 5.19.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Asansol were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.5.1. The details of sampling locations and source and depth wise distribution are given in Table 5.5.1 and 5.5.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.5.3 and 5.5.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.5.5 to 5.5.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.5.2 to 5.5.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Asansol mostly fall within the range 7.17 to 8.08 during pre-monsoon season and 6.02 to 7.93 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 328 to 2310 μS/cm during pre-monsoon season and 292 to 1752 μS/cm during post-monsoon season. About 64% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2975 μS/cm was observed in the sample of open well of Mohishila during pre-monsoon season.

In the metropolitan city of Asansol, the values of total dissolved solids (TDS) in the ground water varies from 210 to 1478 mg/L during pre-monsoon season and 187 to 1121 mg/L during post-monsoon season. Almost all the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L in pre-monsoon season (Table 5.5.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). About 84% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceeds the maximum permissible limit during pre-monsoon (Table 5.5.5).Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Asansol varies from 65 to 420 mg/L during pre-monsoon season and 62 to 340 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre-and post-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 76 to 911 mg/L during pre-monsoon season and 50 to 759 mg/L during post-monsoon season. About 64% of the samples of the metropolitan city of Asansol crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 12% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.5.7). During the post-monsoon season 36% of the samples fall within desirable limit of 300 mg/L and 12% sample crosses the permissible limit of 600 mg/L because of the dilution. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.4(a&b).

In ground water of the metropolitan city of Asansol, the values of calcium range from 14 to 301 mg/L during pre-monsoon season and 10 to 192 mg/L during post-monsoon season. The values of magnesium vary from 10 to 66 mg/L during pre-monsoon season and 6 to 97 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, only two samples exceed the maximum permissible limit of calcium as 200 mg/L and no sample exceeds maximum permissible of magnesium as 75 mg/L in pre-monsoon season. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.5(a&b) and 5.5.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Asansol varies from 12 to 190 mg/L during pre-monsoon season and 9.2 to 164 mg/L during post-monsoon season. Such ground water with high value of sodium is not suitable for irrigation purpose due to sodium hazards.

The concentration of potassium in ground water of the study area varies from

1.2 to 6.1 mg/L during pre-monsoon season and 0.2 to 10 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season.

The concentration of chloride varies from 8 to 330 mg/L during pre-monsoon season and 16 to 286 mg/L during post-monsoon season. More than 92% samples of the metropolitan city falls within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.5.10). No sample of the city exceeds the maximum permissible limit of 1000 mg/L both during pre- and post-monsoon season. The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.7(a&b).

The concentration of sulphate in the metropolitan city varies from 5 to 205 mg/L during pre-monsoon season and 10 to 285 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 92% of the samples analysed fall within the desirable limit of 200 mg/L while 8% of the samples exceed the desirable limit but are within the permissible limit of 400 mg/L during pre- and post-monsoon seasons (Table 5.5.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.8(a&b).

The nitrate content in the metropolitan city of Asansol varies from 0.7 to 220 mg/L during pre-monsoon season and 0.1 to 152 mg/L during post-monsoon season. About 88% of the samples of the metropolitan city of Asansol fall within the permissible limit of 100 mg/L and 12% of samples even cross the permissible limit of 100 mg/L during pre-monsoon season. (Table 5.5.12). Almost same trend was observed during post-monsoon season. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. The higher nitrate concentration at few locations in the study area may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.9(a&b).

The concentration of phosphate in the metropolitan city of Asansol is generally very low at all locations. Phosphate has tendency to get adsorbed or fixed in the soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the study area varies from 0.19 to 1.03 mg/L during pre-monsoon season and 0.22 to 1.45 mg/L during post-monsoon season. Almost all the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.5.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.5.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Asansol, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 84% of the samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in more than 76% of the samples in both the seasons. From the hardness point of view, 76% of the samples exceed the desirable limit and about 64% of the samples are within permissible limit and 12% samples even exceed the permissible limit during pre-monsoon season. The chloride and sulphate contents are within the desirable limits in about more than 92% of the samples. The nitrate content in more than 72% samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in almost all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Asansol shows bacterial contamination in about than 64% of the samples during post-monsoon season indicating the contamination during recharge of ground water.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Asansol are given in Tables 5.5.15 and 5.5.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.5.17 to 5.5.26 and graphically shown in Fig. 5.5.11 to 5.5.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Asansol ranges from 128 to 23300 μg/L during pre-monsoon season (Table 5.5.15) and 310 to 42770 μg/L during post-monsoon season (Table 5.5.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.5.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is evident from the results that 92% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 84% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, no sample falls within the desirable limit and 64% of the samples even exceed the maximum permissible limit (Table 5.5.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata existing in the study area. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 5 to 470 μg/L during pre-monsoon season (Table 5.5.15) and 2 to 64 μg/L during post-monsoon season (Table 5.5.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.5.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is evident from the results that about 52% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 20% of the samples exceed the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.5.18). In post-monsoon season, all samples fall within the desirable limit because of dilution. The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 6 to 381 µg/L during pre-monsoon season (Table 5.5.15) and 2 to 25 µg/L during post-monsoon season during post-monsoon season (Table 5.5.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.5.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limit and 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Asansol, more than 92% of the samples fall below the desirable limit of 50 µg/L and remaining about 8% samples exceed the desirable limit but are within the maximum permissible limit (Table 5.5.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies.

**Chromium (Cr):** The concentration of chromium ranges from 2 to 20 µg/L during pre-monsoon season (Table 5.5.15) and 2 to 8 µg/L during post-monsoon season (Table 5.5.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.5.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Asansol, almost all the samples fall well within the desirable limit for drinking water.

**Lead (Pb):** In the study area, the concentration of lead ranges from 4 to 71 µg/L during pre-monsoon season (Table 5.5.15) and 13 to 91 µg/L during post-monsoon season (Table 5.5.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.5.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Asansol, almost all the samples fall well within the desirable limit for drinking water during pre-monsoon season.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 1 to 9 µg/L during pre-monsoon season (Table 5.5.15) and 1 to 3 µg/L during post-monsoon season (Table 5.5.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.5.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Asansol, almost all the samples fall within the permissible limit of 10 µg/L during both pre- and post-monsoon seasons (Table 5.5.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 300 to 6570 µg/L during pre-monsoon season (Table 5.5.15) and 104 to 821 µg/L during post-monsoon season (Table 5.5.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.5.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Asansol, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996).

**Arsenic (As):** The concentration of arsenic in the study area is not detected during both pre- and post-monsoon seasons (Table 5.5.15 & Table 5.5.16). The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found free from arsenic contamination.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 2.0 μg/L during pre-monsoon season and ND to 1.0 during post-monsoon season (Table 5.5.15 & Table 5.5.16). The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, almost all the samples were found within the limit prescribed by BIS (1991) both in pre- and post-monsoon seasons.

It is clearly evident from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (84% samples), manganese (20% samples), nickel (88% samples) and lead (8% samples) during pre-monsoon season.

# Pesticides

During ground water quality assessment of the metropolitan city of Asansol, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.5.27 and 5.5.28. Out of the seven chlorinated pesticides analysed, only three pesticides (Aldrin, DDT and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of

Asansol, no PAH was detected.

## 5.19.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Asansol are given in Table 5.5.29.

## Salinity

The electrical conductivity value in the metropolitan city of Asansol varies widely from 328 to 2310 μS/cm during pre-monsoon season and 292 to 1752 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.41 to 5.24 during pre-monsoon season and 0.37 to 6.42 during post-monsoon season. The sodium percentage in the study area was found to vary from 11.0 to 75.7% during pre-monsoon season and 11.3 to 82.8 during post-monsoon season. Only one sample of the study area exceeds the recommended value of 60% for irrigation during both pre- and post-monsoon seasons and is not suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at almost all locations.

## Boron

In the present investigation of metropolitan city of Asansol, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.19.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.5.30 and 5.5.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of metropolitan city of

Asansol have been plotted on trilinear diagram for both the surveys (Fig. 5.5.19 and 5.5.20) and results have been summarized in Table 5.5.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Asansol have been plotted on Chadha' diagram (Fig. 5.5.21 and 5.5.22) and results have been summarized in Table 5.5.30. It is evident from the results that majority of the samples of the metropolitan city belong to Group 5 (Ca-Mg-$HCO_3$) or Group 6 (Ca-Mg-Cl-$SO_4$) hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.5.23 and 5.5.24 respectively. It is evident from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Asansol has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.5.25 and 5.5.26) and the results have been summarized in Table 5.5.30. It is evident from the results that the majority of ground water samples of the metropolitan city of Asansol falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Asansol has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.5.31. It is evident from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification.

# 5.20 Dhanbad

## 5.20.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Dhanbad were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.6.1. The details of sampling locations and source and depth wise distribution are given in Table 5.6.1 and 5.6.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.6.3 and 5.6.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.6.5 to 5.6.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.6.2 to 5.6.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Dhanbad fall within the range 6.45 to 7.98 during pre-monsoon season and 5.45 to 7.60 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 382 to 1645 μS/cm during pre-monsoon season and 335 to 1700 μS/cm during post-monsoon season. About 40% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 1700 μS/cm was observed in the sample of open well of Katras during post-monsoon season.

In the metropolitan city of Dhanbad, the values of total dissolved solids (TDS) in the ground water varies from 244 to 1053 mg/L during pre-monsoon season and 214 to 1088 mg/L during post-monsoon season. Almost all the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L in pre-monsoon season (Table 5.6.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). About 64% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceeds the maximum permissible limit during pre-monsoon (Table 5.6.5).Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Dhanbad varies from 54 to 375 mg/L during pre-monsoon season and 45 to 312 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre-and post-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 146 to 647 mg/L during pre-monsoon season and 126 to 782 mg/L during post-monsoon season. About 52% of the samples of the metropolitan city of Dhanbad crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 12% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.6.7). Exactly similar trend was observed during post-monsoon season. The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.4(a&b).

In ground water of the metropolitan city of Dhanbad, the values of calcium range from 31 to 207 mg/L during pre-monsoon season and 21 to 201 mg/L during post-monsoon season. The values of magnesium vary from 7.7 to 75 mg/L during pre-monsoon season and 16 to 110 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, only one sample exceeds the maximum permissible limit of calcium as 200 mg/L and no sample exceeds maximum permissible of magnesium as 75 mg/L in pre-monsoon season. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.5(a&b) and 5.6.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Dhanbad varies from 7 to 100 mg/L during pre-monsoon season and 3.7 to 81 mg/L during post-monsoon season. The concentration of potassium in ground water of the study area varies from 0.1 to 4.7 mg/L during pre-monsoon season and 0.2 to 10 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season.

The concentration of chloride varies from 1 to 171 mg/L during pre-monsoon season and 10 to 215 mg/L during post-monsoon season. All the samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon season (Table 5.6.10). The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.7(a&b).

The sulphate content in ground water of the metropolitan city varies from 3 to 305 mg/L during pre-monsoon season and 15 to 265 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 96% of the samples analysed fall within the desirable limit of 200 mg/L while only one sample exceeds the desirable limit but are within the permissible limit of 400 mg/L during pre- and post-monsoon seasons (Table 5.6.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.8(a&b).

The nitrate content in the metropolitan city of Dhanbad varies from 0.2 to 428 mg/L during pre-monsoon season and 0.4 to 185 mg/L during post-monsoon season. About 92% of the samples of the metropolitan city of Dhanbad fall within the permissible limit of 100 mg/L and 8% of samples even cross the permissible limit of 100 mg/L during pre-monsoon season (Table 5.6.12). Almost same trend was observed during post-monsoon season. The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.9(a&b).

The concentration of phosphate in the metropolitan city of Dhanbad is generally very low except at few locations. Phosphate has a tendency to get adsorbed in the soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the study area varies from 0.01 to 1.11 mg/L during pre-monsoon season and 0.05 to 1.18 mg/L during post-monsoon season. Almost all the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.6.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.6.10(a&b).

The study has clearly indicated that the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 64% of the samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in more than 40% of the samples in both the seasons. From the hardness point of view, 64% of the samples exceed the desirable limit and about 52% of the samples are within permissible limit and 12% sample even exceeds the permissible limit during pre-monsoon season. The chloride and sulphate contents are within the desirable limits in almost all the samples. The nitrate content in more than 88% samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in almost all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the ground water samples of the metropolitan city of Dhanbad shows bacterial contamination in two ground water samples only during pre- and post-monsoon season but within the permissible limit.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Dhanbad are given in Tables 5.6.15 and 5.6.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.6.17 to 5.6.26 and graphically shown in Fig. 5.6.11 to 5.6.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Dhanbad ranges from 196 to 28493 μg/L during pre-monsoon season (Table 5.6.15) and 130 to 6510 μg/L during post-monsoon season (Table 5.6.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.6.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is revealed from the results that 96% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 68% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 12% of the sample falls within the desirable limit and 44% of the samples even exceed the maximum permissible limit because of dilution (Table 5.6.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 12 to 1489 μg/L during pre-monsoon season (Table 5.6.15) and 5 to 484 μg/L during post-monsoon season (Table 5.6.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.6.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is revealed from the results that about 36% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 40% of the samples exceed the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.6.18). In post-monsoon season, 68% of the samples fall within the desirable limit because of dilution effect. High concentration of manganese at few locations may be attributed to reducing condition of water and thereby the dissolution of manganese bearing minerals from the soil strata of the study area. The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 2 to 61 μg/L during pre-monsoon season (Table 5.6.15) and 2 to 15 μg/L during post-monsoon season during post-monsoon season (Table 5.6.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.6.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Dhanbad, almost all the samples fall well within the desirable limit of 50 μg/L for drinking water (Table 5.6.19). As such the ground water of the metropolitan city can be safely used as a source of drinking water supplies.

**Chromium (Cr):** The concentration of chromium ranges from 2 to 9 μg/L during pre-monsoon season (Table 5.6.15) and 2 to 8 μg/L during post-monsoon season (Table 5.6.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.6.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Dhanbad, all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

**Lead (Pb):** In the study area, the concentration of lead ranges from 10 to 43 μg/L during pre-monsoon season (Table 5.6.15) and 15 to 78 μg/L during post-monsoon season (Table 5.6.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.6.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Dhanbad, almost all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

**Cadmium (Cd):** The cadmium content in the study area varies from 2 to 8 μg/L during pre-monsoon season (Table 5.6.15) and 1 to 6 μg/L during post-monsoon season (Table 5.6.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.6.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Dhanbad, all the samples fall within the permissible limit of 10 μg/L during both pre- and post-monsoon seasons (Table 5.6.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 20 to 3610 μg/L during pre-monsoon season (Table 5.6.15) and 112 to 902 μg/L during post-monsoon season (Table 5.6.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.6.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Dhanbad, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996) during both pre- and post-monsoon seasons (Table 5.6.24).

**Arsenic (As):** The concentration of arsenic in the study area ranges from ND to 81 μg/L during pre-monsoon season and ND to 18 during post-monsoon season (Table 5.6.15 & Table 5.6.16). The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, only one the sample was found to exceed the permissible limit for drinking water (BIS, 1991) in pre-monsoon season.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 4.0 μg/L during pre-monsoon season and ND to 2.0 during post-monsoon season (Table 5.6.15 & Table 5.6.16). The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, 24% of the samples were found to cross the limit prescribed by BIS (1991) in pre-monsoon season and only one sample in post-monsoon season. The observed high concentration of mercury few locations may be attributed to site specific activity.

It is clearly revealed from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (68% samples), manganese (40% samples), nickel (all samples), lead (8% samples) and mercury (24% samples) during pre-monsoon season.

# Pesticides

During ground water quality evaluation of the metropolitan city of Dhanbad, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.6.27 and 5.6.28. Out of the seven chlorinated pesticides analysed, only four pesticides (Aldrin, DDT, Endosulphan and Methoxychlor) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at few locations. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Dhanbad, no PAH was detected.

## 5.20.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Dhanbad are given in Table 5.6.29.

## Salinity

The electrical conductivity value in the metropolitan city of Dhanbad varies widely from 382 to 1645 μS/cm during pre-monsoon season and 335 to 1700 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.19 to 1.87 during pre-monsoon season and 0.09 to 1.75 during post-monsoon season. The sodium percentage in the study area was found to vary from 5.1 to 33.0% during pre-monsoon season and 2.5 to 37.1 during post-monsoon season. No sample of the study area has sodium percentage above the recommended value of 60% for irrigation during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Dhanbad, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.20.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.6.30 and 5.6.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Dhanbad have been plotted on trilinear diagram for both the surveys (Fig. 5.6.19 and 5.6.20) and results have been summarized in Table 5.6.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Dhanbad have been plotted on Chadha' diagram (Fig. 5.6.21 and 5.6.22) and results have been summarized in Table 5.6.30. It is revealed from the results that majority of the samples of the metropolitan city belong to Group 6 (Ca-Mg-Cl-$SO_4$) or Group 5 (Ca-Mg-$HCO_3$) hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.6.23 and 5.6.24 respectively. . It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Dhanbad has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.6.25 and 5.6.26) and the results have been summarized in Table 5.6.30. It is revealed from the results that the majority of ground water samples of the metropolitan city of Dhanbad falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Dhanbad has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.6.31**.** It is revealed from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to medium alkalinity water as per alkalinity classification**.**

# 5.21 Jamshedpur

## 5.21.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Jamshedpur were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.7.1. The details of sampling locations and source and depth wise distribution are given in Table 5.7.1 and 5.7.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.7.3 and 5.7.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.7.5 to 5.7.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.7.2 to 5.7.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Jamshedpur fall within the range 6.25 to 7.52 during pre-monsoon season and 5.64 to 6.86 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 348 to 2040 μS/cm during pre-monsoon season and 510 to 1890 μS/cm during post-monsoon season. About 56% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2040 μS/cm was observed in the sample of hand pump of Sita Path during pre-monsoon season.

In the metropolitan city of Jamshedpur, the values of total dissolved solids (TDS) in the ground water varies from 223 to 1306 mg/L during pre-monsoon season and 326 to 1210 mg/L during post-monsoon season. Almost all the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L in pre-monsoon season (Table 5.7.5). The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). About 68% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceeds the maximum permissible limit during pre-monsoon. Almost similar trend was observed in the post-monsoon season (Table 5.7.5). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Jamshedpur varies from 100 to 325 mg/L during pre-monsoon season and 142 to 322 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre-and post-monsoon season. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 130 to 792 mg/L during pre-monsoon season and 216 to 749 mg/L during post-monsoon season. About 60% of the samples of the metropolitan city of Jamshedpur crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 8% sample crosses the permissible limit of 600 mg/L during pre-monsoon season (Table 5.7.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.4(a&b).

In ground water of the metropolitan city of Jamshedpur, the values of calcium range from 29 to 253 mg/L during pre-monsoon season and 42 to 232 mg/L during post-monsoon season. The values of magnesium vary from 14 to 58 mg/L during pre-monsoon season and 18 to 54 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, only two samples exceed the maximum permissible limit of calcium as 200 mg/L and no sample exceeds maximum permissible of magnesium as 75 mg/L in pre- and post-monsoon seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.5(a&b) and 5.7.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Jamshedpur varies from 11 to 102 mg/L during pre-monsoon season and 13 to 93 mg/L during post-monsoon season. Ground water with high value of sodium is not suitable for irrigation purpose due to sodium hazards.

The concentration of potassium in ground water of the study area varies from

0.1 to 4.9 mg/L during pre-monsoon season and 0.1 to 9.1 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season.

The concentration of chloride varies from 15 to 235 mg/L during pre-monsoon season and 24 to 224 mg/L during post-monsoon season. All the samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon seasons (Table 5.7.10). The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.7(a&b).

The sulphate content in ground water generally occurs as soluble salts of calcium, magnesium and sodium. The concentration of sulphate in the metropolitan city varies from 3 to 210 mg/L during pre-monsoon season and 5 to 252 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, 92% of the samples analysed fall within the desirable limit of 200 mg/L while only two samples exceed the desirable limit but are within the permissible limit of 400 mg/L during pre- and post-monsoon seasons (Table 5.7.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.8(a&b).

The nitrate content in the metropolitan city of Jamshedpur varies from 0.2 to 442 mg/L during pre-monsoon season and 0.4 to 24 mg/L during post-monsoon season. About 84% of the samples of the metropolitan city of Jamshedpur fall within the permissible limit of 100 mg/L and 16% of samples even cross the permissible limit of 100 mg/L during pre-monsoon season. All samples fall within the desirable limit of 45 mg/L because of the dilution (Table 5.7.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.9(a&b). The higher nitrate concentration at few locations in the study area may be attributed due to combined effect of contamination from domestic sewage, livestock rearing landfills and runoff from fertilized fields.

The concentration of phosphate in the metropolitan city of Jamshedpur is generally very low. Phosphate has tendency to get adsorbed or fixed in the soils, as a result the concentration of phosphate in ground water is usually low.

The fluoride content in the ground water of the study area varies from 0.14 to 1.10 mg/L during pre-monsoon season and 0.20 to 0.82 mg/L during post-monsoon season. Almost all the samples of the metropolitan city falls within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.7.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.7.10(a&b).

The study has clearly indicated that the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 68% of the samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in more than 40% of the samples in pre-monsoon season. From the hardness point of view, 68% of the samples exceed the desirable limit and about 60% of the samples are within permissible limit and 8% samples even exceed the permissible limit during pre-monsoon season. The chloride and sulphate contents are within the desirable limits in almost all the samples. The nitrate content in more than 80% samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in almost all of the samples in pre-and post-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Jamshedpur reveals that all samples of the study area are free from bacterial contamination during pre- and post-monsoon seasons.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Jamshedpur are given in Tables 5.7.15 and 5.7.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.7.17 to 5.7.26 and graphically shown in Fig. 5.7.11 to 5.7.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Jamshedpur ranges from 164 to 8056 μg/L during pre-monsoon season (Table 5.7.15) and 450 to 53680 μg/L during post-monsoon season (Table 5.7.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.7.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is revealed from the results that 96% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 56% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, all the samples of the metropolitan city exceed the desirable limit and 92% of the samples exceed the maximum permissible limit (Table 5.7.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata in the study area and other anthropogenic activities. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 12 to 1678 μg/L during pre-monsoon season (Table 5.7.15) and 45 to 1482 μg/L during post-monsoon season (Table 5.7.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.7.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is revealed from the results that about 12% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 56% of the samples exceed the maximum permissible limit of 300 μg/L during pre- and post-monsoon season (Table 5.7.18). High concentration of manganese may be attributed to the dissolution of manganese bearing minerals from the soil strata in the study area and other anthropogenic activities. The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 3 to 145 µg/L during pre-monsoon season (Table 5.7.15) and 12 to 111 µg/L during post-monsoon season during post-monsoon season (Table 5.7.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.7.13. The Bureau of Indian Standards has recommended 50 µg/L as the desirable limit and 1500 µg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 µg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Jamshedpur, 88% of the samples fall well within the desirable limit of 50 µg/L for drinking water (Table 5.7.19).

**Chromium (Cr):** The concentration of chromium ranges from 2 to 19 µg/L during pre-monsoon season (Table 5.7.15) and 2 to 9 µg/L during post-monsoon season (Table 5.7.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.7.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jamshedpur, all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

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**Lead (Pb):** In the study area, the concentration of lead ranges from 12 to 48 µg/L during pre-monsoon season (Table 5.7.15) and 4 to 52 µg/L during post-monsoon season (Table 5.7.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.7.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Jamshedpur, almost all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 5 to 12 µg/L during pre-monsoon season (Table 5.7.15) and 2 to 6 µg/L during post-monsoon season (Table 5.7.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.7.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jamshedpur, almost all the samples fall within the permissible limit of 10 µg/L during both pre- and post-monsoon seasons (Table 5.7.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 184 to 3332 µg/L during pre-monsoon season (Table 5.7.15) and 24 to 3140 µg/L during post-monsoon season (Table 5.7.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.7.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Jamshedpur, almost all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996) during both pre- and post-monsoon seasons (Table 5.7.24).

**Arsenic (As):** The concentration of arsenic in the study area is not detected except three locations during both pre- and post-monsoon seasons (Table 5.7.15 & Table 5.7.16). The Bureau of Indian Standards has prescribed 50 µg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 µg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found free from arsenic contamination.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 2.0 µg/L during pre-monsoon season and ND to 1.0 during post-monsoon season (Table 5.7.15 & Table 5.7.16). The Bureau of Indian Standards has prescribed 1 µg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 µg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, all the samples were found within the desirable limit prescribed by BIS (1991) except at one location in pre-monsoon season.

It is clearly revealed from the above discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (56% samples), manganese (56% samples), nickel (all samples) and cadmium (8% samples) during pre-monsoon season.

# Pesticides

During ground water quality study of the metropolitan city of Jamshedpur, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.7.27 and 5.7.28. Out of the thirteen chlorinated pesticides analysed, only four pesticides (Aldrin, DDT, Endosulphan and Methoxychlor) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at few locations. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Jamshedpur, no PAH was detected.

## 5.21.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Jamshedpur are given in Table 5.7.29.

## Salinity

The electrical conductivity values in the metropolitan city of Jamshedpur varies widely from 348 to 2040 μS/cm during pre-monsoon season and 510 to 1890 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.39 to 2.08 during pre-monsoon season and 0.38 to 1.95 during post-monsoon season. The sodium percentage in the study area was found to vary from 10.4 to 34.7% during pre-monsoon season and 10.9 to 36.1 during post-monsoon season. All the samples have percentage sodium below the recommended value of 60% for irrigation during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Jamshedpur, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.21.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.7.30 and 5.7.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Jamshedpur have been plotted on trilinear diagram for both the surveys (Fig. 5.7.19 and 5.7.20) and results have been summarized in Table 5.7.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Jamshedpur have been plotted on Chadha' diagram (Fig. 5.7.21 and 5.7.22) and results have been summarized in Table 5.7.30. It is revealed from the results that majority of the samples of the metropolitan city belong to Group 5 (Ca-Mg-$HCO_3$) or Group 6 (Ca-Mg-Cl-$SO_4$) hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.7.23 and 5.7.24 respectively. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Jamshedpur has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.7.25 and 5.7.26) and the results have been summarized in Table 5.7.30. It is revealed from the results that the majority of ground water samples of the metropolitan city of Jamshedpur falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Jamshedpur has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.7.31. It is revealed from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to medium alkalinity water as per alkalinity classification.

# 5.22 Kolkata

## 5.22.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Kolkata were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.8.1. The details of sampling locations and source and depth wise distribution are given in Table 5.8.1 and 5.8.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.8.3 and 5.8.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.8.5 to 5.8.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.8.2 to 5.8.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Kolkata fall within the range 6.53 to 7.35 during pre-monsoon season and 6.04 to 7.52 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 960 to 3090 μS/cm during pre-monsoon season and 780 to 3030 μS/cm during post-monsoon season. About 84% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 3090 μS/cm was observed in the sample of hand pump of Santosh Pur during pre-monsoon season.

In the metropolitan city of Kolkata, the values of total dissolved solids (TDS) in the ground water varies from 614 to 1978 mg/L during pre-monsoon season and 499 to 1939 mg/L during post-monsoon season. The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). All the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceed the maximum permissible limit during pre-monsoon season. Almost similar trend was observed in the post-monsoon season (Table 5.8.5). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Kolkata varies from 200 to 552 mg/L during pre-monsoon season and 148 to 436 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre- and post-monsoon season (Table 5.8.6). The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 203 to 995 mg/L during pre-monsoon season and 179 to 1002 mg/L during post-monsoon season. About 48% of the samples of the metropolitan city of Kolkata crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and 36% sample crosses the permissible limit of 600 mg/L during pre-monsoon season. Almost similar trend was observed in the post-monsoon season (Table 5.8.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.4(a&b).

In ground water of the metropolitan city of Kolkata, the values of calcium range from 42 to 322 mg/L during pre-monsoon season and 41 to 245 mg/L during post-monsoon season. The values of magnesium vary from 22 to 66 mg/L during pre-monsoon season and 15 to 132 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, 32% of the samples exceed the maximum permissible limit of calcium as 200 mg/L and no sample exceeds maximum permissible of magnesium as 75 mg/L in pre-monsoon season. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.5(a&b) and 5.8.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Kolkata varies from 44 to 384 mg/L during pre-monsoon season and 48 to 292 mg/L during post-monsoon season. Ground water with high value of sodium is not suitable for irrigation purpose due to sodium hazards.

The concentration of potassium in ground water of the study area ranges from 1.2 to 9.4 mg/L during pre-monsoon season and 2.1 to 5.9 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season.

The concentration of chloride varies from 45 to 805 mg/L during pre-monsoon season and 62 to 825 mg/L during post-monsoon season. About 44% of the samples of the metropolitan city fall within the desirable limit of 250 mg/L and 56% samples exceed the desirable limit during both pre- and post-monsoon seasons (Table 5.8.10). The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.7(a&b).

The concentration of sulphate in the metropolitan city varies from 1 to 51 mg/L during pre-monsoon season and 1.5 to 50 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, all samples analysed fall within the desirable limit of 200 mg/L during pre- and post-monsoon seasons (Table 5.8.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.8(a&b).

The nitrate content in the metropolitan city of Kolkata varies from 0.07 to 1.22 mg/L during pre-monsoon season and 0.44 to 1.32 mg/L during post-monsoon season. All samples fall within the desirable limit of 45 mg/L during pre- and post-monsoon seasons (Table 5.8.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.9(a&b).

The concentration of phosphate in the metropolitan city of Kolkata is generally very low except at few locations. Phosphate has tendency to get adsorbed or fixed in the soils, as a result the concentration of phosphate in ground water is usually low, but various chemical processes in soil strata may induce the mobility of phosphate in sub-soil and ground water.

The fluoride content in the ground water of the study area varies from 0.22 to 1.35 mg/L during pre-monsoon season and 0.20 to 0.71 mg/L during post-monsoon season. Almost all the samples of the metropolitan city falls within the desirable limit of 1.0 mg/L during pre- as well as post-monsoon season (Table 5.8.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.8.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Kolkata, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in all samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in all samples in pre-monsoon season. From the hardness point of view, 84% of the samples exceed the desirable limit and about 48% of the samples are within permissible limit and 36% samples even exceed the permissible limit during pre-monsoon season. The chloride content in about 44% of the samples of the metropolitan city fall within the desirable limit and 56% samples exceed the desirable limit during both pre- and post-monsoon seasons. The sulphate content is within the desirable limit in all the samples. The nitrate content in all samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in almost all of the samples in pre-and post-monsoon seasons. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Kolkata reveals bacterial contamination in four samples only during pre-monsoon seasons but within the permissible limit.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Kolkata are given in Tables 5.8.15 and 5.8.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.8.17 to 5.8.26 and graphically shown in Fig. 5.8.11 to 5.8.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Kolkata ranges from 275 to 21387 μg/L during pre-monsoon season (Table 5.8.15) and 437 to 5305 μg/L during post-monsoon season (Table 5.8.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.8.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is revealed from the results that 96% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 64% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 96% samples of the metropolitan city exceed the desirable limit and 72% of the samples exceed the maximum permissible limit (Table 5.8.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata in the study area. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 11 to 889 μg/L during pre-monsoon season (Table 5.8.15) and 16 to 985 μg/L during post-monsoon season (Table 5.8.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.8.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is revealed from the results that about 24% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 64% of the samples exceed the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.8.18). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 3 to 54 μg/L during pre-monsoon season (Table 5.8.15) and 2 to 153 μg/L during post-monsoon season during post-monsoon season (Table 5.8.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.8.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Kolkata, almost all of the samples fall well within the desirable limit of 50 μg/L for drinking water (Table 5.8.19).

**Chromium (Cr):** The concentration of chromium ranges from 1 to 12 μg/L during pre-monsoon season (Table 5.8.15) and 1 to 6 μg/L during post-monsoon season (Table 5.8.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.8.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kolkata, all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

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**Lead (Pb):** In the study area, the concentration of lead ranges from 9 to 46 μg/L during pre-monsoon season (Table 5.8.15) and 16 to 85 μg/L during post-monsoon season (Table 5.8.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.8.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Kolkata, all the samples fall well within the desirable limit for drinking water during pre-monsoon season.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 8 to 28 μg/L during pre-monsoon season (Table 5.8.15) and 1 to 3 μg/L during post-monsoon season (Table 5.8.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.8.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kolkata, 72% of the samples fall within the permissible limit of 10 μg/L and 28% samples exceed the permissible limit during pre-monsoon season. In post-monsoon season, all samples fall within the permissible limit because of dilution effect (Table 5.8.23). Cadmium may enter the water supply from variety of industrial applications including mining and smelting, electroplating, and pigment and plasticizer production, and leachates from landfills. Drinking water is generally contaminated with galvanized iron pipe and plated plumbing fittings of the water distribution system. USEPA has classified cadmium as a probable human carcinogen based on positive carcinogenicity testing.

**Zinc (Zn):** The concentration of zinc in the study area ranges from 213 to 12264 μg/L during pre-monsoon season (Table 5.8.15) and 210 to 9170 μg/L during post-monsoon season (Table 5.8.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.8.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kolkata, 80% of the samples were found within the desirable limit prescribed by BIS (1991) during pre-monsoon season (Table 5.8.24).

**Arsenic (As):** The concentration of arsenic in the study area ranges from ND to 3717 μg/L during pre-monsoon season and ND to 65 during post-monsoon season (Table 5.8.15 & Table 5.8.16). The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, 64% of the samples fall within the permissible limit for drinking water and 36% samples cross the permissible limit during pre-monsoon season. The arsenic contamination in the study area may be attributed to the presence of geological material containing arsenic minerals.

**Mercury (Hg):** The concentration of mercury in the study area ranges from 1 to 5 μg/L during pre-monsoon season and ND to 3.0 during post-monsoon season (Table 5.8.15 & Table 5.8.16). The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, 28% of the samples were found within the permissible limit prescribed by BIS (1991) and 72% samples cross the permissible limit in pre-monsoon season. The mercury contamination in the study area may be attributed to the industrial activities.

It is clearly revealed from the above discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (64% samples), manganese (64% samples), nickel (96% samples), cadmium (28% samples), arsenic (36%) and mercury (72%) during pre-monsoon season.

## Pesticides

During ground water quality assessment of the metropolitan city of Kolkata, all the twenty five samples were analysed for organo-chlorinated pesticides Aldrin , Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.8.27 and 5.8.28. Out of the thirteen chlorinated pesticides analysed, only three pesticides (Aldrin, DDT, and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits except at few locations. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Kolkata, no PAH was detected.

## 5.22.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Kolkata are given in Table 5.8.29.

## Salinity

The electrical conductivity value in the metropolitan city of Kolkata varies widely from 960 to 3090 μS/cm during pre-monsoon season and 780 to 3030 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.98 to 6.13 during pre-monsoon season and 1.03 to 5.51 during post-monsoon season. The sodium percentage in the study area was found to vary from 18.9 to 60.3 during pre-monsoon season and 20.8 to 55.7 during post-monsoon season. All samples have sodium percentage below the recommended value of 60% for irrigation during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Kolkata, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.22.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.8.30 and 5.8.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Kolkata have been plotted on trilinear diagram for both the surveys (Fig. 5.8.19 and 5.8.20) and results have been summarized in Table 5.8.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Kolkata have been plotted on Chadha' diagram (Fig. 5.8.21 and 5.8.22) and results have been summarized in Table 5.8.30. It is revealed from the results that majority of the samples of the metropolitan city belong to Group 6 (Ca-Mg-Cl-$SO_4$) or Group 5 (Ca-Mg-$HCO_3$) hydrochemical facies in both pre- and post-monsoon season.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.8.23 and 5.8.24 respectively. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-Cl-$SO_4$ or Ca-Mg-$HCO_3$ hydrochemical facies in both pre- and post-monsoon season.

# U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Kolkata has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.8.25 and 5.8.26) and the results have been summarized in Table 5.8.30. It is revealed from the results that the majority of ground water samples of the metropolitan city of Kolkata falls under water types C3-S1 followed by C4-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Kolkata has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.8.31**.** It is revealed from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.23 Amritsar

# 5.23.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Amritsar were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.9.1. The details of sampling locations and source and depth wise distribution are given in Table 5.9.1 and 5.9.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.9.3 and 5.9.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.9.5 to 5.9.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.9.2 to 5.9.10.

# General Characteristics

The pH values in the ground water of metropolitan city of Amritsar fall within the range 6.48 to 6.96 during pre-monsoon season and 6.02 to 6.96 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 555 to 1986 μS/cm during pre-monsoon season and 490 to 1916 μS/cm during post-monsoon season. About

40% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 1986 μS/cm was observed in the sample of hand pump of Kala Ghanlipur during pre-monsoon season.

In the metropolitan city of Amritsar, the values of total dissolved solids (TDS) in the ground water varies from 355 to 1271 mg/L during pre-monsoon season and 314 to 1226 mg/L during post-monsoon season. The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). About 60% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceeds the maximum permissible limit during pre-monsoon season (Table 5.9.5). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Amritsar varies from 185 to 482 mg/L during pre-monsoon season and 146 to 396 mg/L during post-monsoon season. No sample exceeds the maximum permissible limit of 600 mg/L during pre- and post-monsoon season (Table 5.9.6). The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 164 to 486 mg/L during pre-monsoon season and 149 to 481 mg/L during post-monsoon season. About 32% of the samples of the metropolitan city of Amritsar crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and no sample crosses the permissible limit of 600 mg/L during pre-and post-monsoon seasons (Table 5.9.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.4(a&b).

In ground water of the metropolitan city of Amritsar, the values of calcium range from 10 to 165 mg/L during pre-monsoon season and 30 to 168 mg/L during post-monsoon season. The values of magnesium vary from 18 to 57 mg/L during pre-monsoon season and 6.9 to 49 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, no sample exceeds maximum permissible of calcium as 200 mg/L and magnesium as 75 mg/L in both the pre- and post-monsoon seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.5(a&b) and 5.9.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Amritsar varies from 12 to 196 mg/L during pre-monsoon season and 9.4 to 194 mg/L during post-monsoon season. Ground water with high value of sodium is not suitable for irrigation purpose due to sodium hazards.

The concentration of potassium in ground water of the study area ranges from 1.1 to 10 mg/L during pre-monsoon season and 4 to 26 mg/L during post-monsoon season.

As per EEC criteria, only one sample exceeds the guideline level of 10 mg/L during post-monsoon season.

The concentration of chloride varies from 5 to 148 mg/L during pre-monsoon season and 2 to 130 mg/L during post-monsoon season. All samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon seasons (Table 5.9.10). The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.7(a&b).

The concentration of sulphate in the metropolitan city varies from 6.5 to 158 mg/L during pre-monsoon season and 6 to 180 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, all samples analysed fall within the desirable limit of 200 mg/L during pre- and post-monsoon seasons (Table 5.9.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.8(a&b).

The nitrate content in the metropolitan city of Amritsar varies from 0.3 to 133 mg/L during pre-monsoon season and 0.4 to 185 mg/L during post-monsoon season. About 88% of the samples fall within the desirable limit of 45 mg/L and 12% samples exceed the maximum permissible limit of 100 mg/L during pre-monsoon season (Table 5.9.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.9(a&b). The higher nitrate concentration at few locations in the study area may be attributed due to combined effect of contamination from domestic sewage and livestock rearing landfills.

The concentration of phosphate in the metropolitan city of Amritsar is generally very low at all locations. Phosphate has tendency to get adsorbed or fixed in the soils, as a result the concentration of phosphate in ground water is usually low.

The fluoride content in the ground water of the study area varies from 0.21 to 1.28 mg/L during pre-monsoon season and 0.01 to 4.56 mg/L during post-monsoon season. About 84% of the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L during pre-monsoon season (Table 5.9.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.9.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Amritsar, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 60% of samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in almost all samples in pre-monsoon season. From the hardness point of view, 32% of the samples exceed the desirable limit and no sample exceeds the permissible limit during pre-monsoon season. The chloride and sulphate content are within the desirable limit in all the samples. The nitrate content in 88% of the samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in 84% of the samples in pre-and post-monsoon seasons. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Amritsar reveals the study area free from bacterial contamination during pre- and post-monsoon seasons.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Amritsar are given in Tables 5.9.15 and 5.9.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.9.17 to 5.9.26 and graphically shown in Fig. 5.9.11 to 5.9.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Amritsar ranges from 101 to 2591 μg/L during pre-monsoon season (Table 5.9.15) and 85 to 12877 μg/L during post-monsoon season (Table 5.9.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.9.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is revealed from the results that 76% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 44% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 96% samples of the metropolitan city exceed the desirable limit and 88% of the samples exceed the maximum permissible limit (Table 5.9.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata in the study area. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 13 to 722 μg/L during pre-monsoon season (Table 5.9.15) and 33 to 778 μg/L during post-monsoon season (Table 5.9.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.9.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is revealed from the results that about 40% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 20% of the samples exceed the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.9.18). The presence of manganese above permissible limit of drinking water often imparts alien taste to water. It also has adverse effects on domestic uses and water supply structures.

**Copper (Cu):** The concentration of copper ranges from 2 to 318 μg/L during pre-monsoon season (Table 5.9.15) and 3 to 162 μg/L during post-monsoon season during post-monsoon season (Table 5.9.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.9.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Amritsar, 84% of the samples fall well within the desirable limit of 50 µg/L for drinking water (Table 5.9.19).

**Chromium (Cr):** The concentration of chromium ranges from 2 to 6 µg/L during pre-monsoon season (Table 5.9.15) and 2 to 13 µg/L during post-monsoon season (Table 5.9.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.9.15. A concentration of 50 µg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Amritsar, all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

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**Lead (Pb):** In the study area, the concentration of lead ranges from 9 to 173 µg/L during pre-monsoon season (Table 5.9.15) and 12 to 72 µg/L during post-monsoon season (Table 5.9.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.9.16. The Bureau of Indian Standards has prescribed 50 µg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Amritsar, 88% of the samples fall well within the desirable limit for drinking water during pre-monsoon season.

**Cadmium (Cd):** The cadmium content in the study area varies from 4 to 11 µg/L during pre-monsoon season (Table 5.9.15) and 1 to 5 µg/L during post-monsoon season (Table 5.9.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.9.17. The Bureau of Indian Standards has prescribed 10 µg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 µg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Amritsar, almost all the samples fall within the permissible limit of 10 µg/L during pre- and post-monsoon seasons (Table 5.9.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 128 to 1033 µg/L during pre-monsoon season (Table 5.9.15) and 126 to 11203 µg/L during post-monsoon season (Table 5.9.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.9.18. The Bureau of Indian Standards has prescribed 5000 µg/L zinc as the desirable limit and 15000 µg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 µg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Amritsar, all the samples were found within the desirable limit prescribed by BIS (1991) during pre-monsoon season (Table 5.9.24).

**Arsenic (As):** The concentration of arsenic in the study area ranges from ND to 37 µg/L during pre-monsoon season and ND to 12 during post-monsoon season (Table 5.9.15 & Table 5.9.16). The Bureau of Indian Standards has prescribed 50 µg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 µg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples fall within the permissible limit for drinking water during pre- and post-monsoon seasons.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 1.0 µg/L during pre-monsoon season and is not detected during post-monsoon season (Table 5.9.15 & Table 5.9.16). The Bureau of Indian Standards has prescribed 1 µg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 1996). In the study area, all the samples were found within the permissible limit prescribed by BIS (1991) during pre- and post-monsoon seasons.

It is clearly revealed from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (44% samples), manganese (20% samples), nickel (92% samples) and lead (12% samples) during pre-monsoon season.

## Pesticides

During present investigation of ground water quality of the metropolitan city of Amritsar, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.9.27 and 5.9.28. Out of the seven chlorinated pesticides analysed, only three pesticides (Aldrin, DDT, and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of all the pesticides were within the permissible limits. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have traveled through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

## Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Amritsar, no PAH was detected.

# 5.23.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Amritsar are given in Table 5.9.29.

## Salinity

The electrical conductivity values in the metropolitan city of Amritsar varies widely from 555 to 1986 μS/cm during pre-monsoon season and 490 to 1916 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.30 to 4.47 during pre-monsoon season and 0.27 to 4.54 during post-monsoon season. The sodium percentage in the study area was found to vary from 8.5 to 58.8 during pre-monsoon season and 9.8 to 55.5 during post-monsoon season. All samples of the study area have sodium percentage below the recommended value of 60% for irrigation during both pre- and post-monsoon seasons and are suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Amritsar, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.23.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.9.30 and 5.9.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Amritsar have been plotted on trilinear diagram for both the surveys (Fig. 5.9.19 and 5.9.20) and results have been summarized in Table 5.9.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

## Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Amritsar have been plotted on Chadha' diagram (Fig. 5.9.21 and 5.9.22) and results have been summarized in Table 5.9.30. It is revealed from the results that majority of the samples of the metropolitan city belong to Group 5 (Ca-Mg-$HCO_3$) or Group 6 (Ca-Mg-Cl-$SO_4$)

hydrochemical facies in both pre- and post-monsoon seasons.

## Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.9.23 and 5.9.24 respectively. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon seasons.

## U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Amritsar has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.9.25 and 5.9.26) and the results have been summarized in Table 5.9.30. It is revealed from the results that the majority of ground water samples of the metropolitan city of Amritsar falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

## Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Amritsar has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.9.31**.** It is revealed from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.24 Kanpur

## 5.24.1 Water Quality Evaluation for Drinking Purpose

Twenty five ground water samples from the metropolitan city Kanpur were collected each during pre- as well as post-monsoon seasons during the year 2006 from various abstraction sources being used for drinking purposes. The location of sampling sites is shown in Fig. 5.10.1. The details of sampling locations and source and depth wise distribution are given in Table 5.10.1 and 5.10.2 respectively. The hydro-chemical data for the two sets of samples collected during pre- and post-monsoon seasons are presented in Table 5.10.3 and 5.10.4 respectively. Distribution of different water quality constituents with depth and season are given in Table 5.10.5 to 5.10.13 and distribution maps are presented in the form of contour diagrams in Figs. 5.10.2 to 5.10.10.

## General Characteristics

The pH values in the ground water of metropolitan city of Kanpur fall within the range 6.56 to 7.08 during pre-monsoon season and 6.60 to 7.61 during post-monsoon season. The pH values for most of the samples are well within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The electrical conductivity and dissolved salt concentrations are directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of the metropolitan city vary widely from 698 to 2680 μS/cm during pre-monsoon season and 552 to 2482 μS/cm during post-monsoon season. About 72% of the samples have conductivity value above 1000 μS/cm during pre-monsoon season. The maximum conductivity value of 2680 μS/cm was observed in the sample of hand pump of Nankari Basti during pre and post-monsoon seasons.

In the metropolitan city of Kanpur, the values of total dissolved solids (TDS) in the ground water varies from 447 to 1715 mg/L during pre-monsoon season and 353 to 1588 mg/L during post-monsoon season. The TDS distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.2(a&b). Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). About 88% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L and no sample exceeds the maximum permissible limit during pre-monsoon season (Table 5.10.5). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991).

The alkalinity value in the ground water of metropolitan city of Kanpur varies from 212 to 638 mg/L during pre-monsoon season and 178 to 440 mg/L during post-monsoon season. Only one sample exceeds the maximum permissible limit of 600 mg/L during pre-monsoon season (Table 5.10.6). Alkalinity in natural water is mainly due to presence of carbonates, bicarbonates and hydroxides. The alkalinity distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.3(a&b).

The presence of calcium and magnesium along with their carbonates, sulphates and chlorides are the main cause of hardness in the water. A limit of 300 mg/L as desirable limit and 600 mg/L as permissible limit has been recommended for drinking water (BIS, 1991). The total hardness values in the study area range from 231 to 781 mg/L during pre-monsoon season and 208 to 725 mg/L during post-monsoon season. About 52% of the samples of the metropolitan city of Kanpur crosses the desirable limit of 300 mg/L but are well within the permissible limit of 600 mg/L and two sample cross the permissible limit of 600 mg/L during pre-monsoon season (Table 5.10.7). The hardness distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.4(a&b).

In ground water of the metropolitan city of Kanpur, the values of calcium range from 43 to 184 mg/L during pre-monsoon season and 34 to 168 mg/L during post-monsoon season. The values of magnesium vary from 15 to 82 mg/L during pre-monsoon season and 16 to 78 mg/L during post-monsoon season. The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. Further, no sample exceeds maximum permissible limit of calcium as 200 mg/L and only two samples exceed the permissible limit of magnesium as 75 mg/L in both the pre- and post-monsoon seasons. The calcium and magnesium distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.5(a&b) and 5.10.6(a&b) respectively.

The concentration of sodium in the metropolitan city of Kanpur varies from 8.7 to 198 mg/L during pre-monsoon season and 8.0 to 192 mg/L during post-monsoon season. Ground water with high value of sodium is not suitable for irrigation purpose due to sodium hazards.

The concentration of potassium in ground water of the study area ranges from 1.9 to 8.1 mg/L during pre-monsoon season and 0.9 to 8.4 mg/L during post-monsoon season. As per EEC criteria, no sample exceeds the guideline level of 10 mg/L during pre- and post-monsoon season.

The concentration of chloride varies from 5 to 255 mg/L during pre-monsoon season and 2 to 266 mg/L during post-monsoon season. Almost all samples of the metropolitan city fall within the desirable limit of 250 mg/L during both pre- and post-monsoon seasons (Table 5.10.10). The chloride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.7(a&b).

The concentration of sulphate in the metropolitan city varies from 3 to 202 mg/L during pre-monsoon season and 50 to 252 mg/L during post-monsoon season. Bureau of Indian standard has prescribed 200 mg/L as the desirable limit and 400 mg/L as the permissible limit for sulphate in drinking water. In the study area, almost all samples analysed fall within the desirable limit of 200 mg/L during pre- and post-monsoon seasons (Table 5.10.11). The sulphate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.8(a&b).

The nitrate content in the metropolitan city of Kanpur varies from 1.3 to 102 mg/L during pre-monsoon season and 0.4 to 95 mg/L during post-monsoon season. About 96% of the samples fall within the desirable limit of 45 mg/L and only one sample exceeds the maximum permissible limit of 100 mg/L during pre-monsoon season (Table 5.10.12). The nitrate distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.9(a&b).

The concentration of phosphate in the metropolitan city of Kanpur is generally very low. Phosphate has tendency to get adsorbed or fixed in the soils, as a result the concentration of phosphate in ground water is usually low.

The fluoride content in the ground water of the study area varies from 0.01 to 2.00 mg/L during pre-monsoon season and 0.01 to 1.54 mg/L during post-monsoon season. About 84% of the samples of the metropolitan city fall within the desirable limit of 1.0 mg/L and 12% of the samples exceed the maximum permissible limit of 1.5 mg/L during pre-monsoon season (Table 5.10.13). The fluoride distribution maps for the pre- and post monsoon seasons are shown in Fig. 5.10.10(a&b).

From the above discussion, it is clearly indicated that in the metropolitan city of Kanpur, the concentration of total dissolved solids exceeds the desirable limit of 500 mg/L in 88% of samples but falls within permissible limit. The alkalinity values also exceed the desirable limit in almost all samples in pre-monsoon season. From the hardness point of view, 60% of the samples exceed the desirable limit and only two samples exceed the permissible limit during pre-monsoon season. The chloride and sulphate content are within the desirable limit in almost all the samples. The nitrate content in 96% of the samples is well within the desirable limit. The concentration of fluoride is well within the desirable limit in 84% of the samples in pre-monsoon season. The violation of BIS limit could not be ascertained for sodium and potassium as no permissible limit for these constituents has been prescribed in BIS drinking water specifications.

# Bacteriological Parameters

The bacteriological analysis of the samples collected from the metropolitan city of Kanpur reveals bacterial contamination in only three samples of the study area during pre-monsoon season but within the permissible limit.

# Heavy Metals

Heavy metals are not biodegradable and enter the food chain through a number of pathways causing progressive toxicity due to the accumulation in human and animal organs during their life span on long term exposure to contaminated environments. The major sources of heavy metals in ground water include weathering of rock minerals, discharge of sewage and other waste effluents on land and runoff water. The trace element data of ground water samples collected during pre- and post-monsoon seasons from the metropolitan city of Kanpur are given in Tables 5.10.15 and 5.10.16 respectively. The distribution of different metals with depth and season are presented in Tables 5.10.17 to 5.10.26 and graphically shown in Fig. 5.10.11 to 5.10.18. The toxic effects of these metals and extent of their contamination in ground water is discussed in the following sections.

**Iron (Fe):** The concentration of iron in the ground water of the metropolitan city of Kanpur ranges from 184 to 9923 μg/L during pre-monsoon season (Table 5.10.15) and 32 to 5974 μg/L during post-monsoon season (Table 5.10.16). The distribution of iron at different sites during pre- and post-monsoon season is shown in Fig. 5.10.11. The Bureau of Indian Standards has recommended 300 μg/L as the desirable limit and 1000 μg/L as the maximum permissible limit for iron in drinking water (BIS, 1991). It is revealed from the results that 84% of the samples of the metropolitan city exceed the desirable limit of 300 μg/L and 60% of the samples exceed the maximum permissible limit of 1000 μg/L in pre-monsoon season. While in post-monsoon season, 76% samples of the metropolitan city exceed the desirable limit and 36% of the samples exceed the maximum permissible limit (Table 5.10.17). High concentration of iron may be attributed to the dissolution of iron bearing minerals from the soil strata. High concentrations of iron generally cause inky flavour, bitter and astringent taste to water.

**Manganese (Mn):** The concentration of manganese ranges from 6 to 287 μg/L during pre-monsoon season (Table 5.10.15) and 10 to 707 μg/L during post-monsoon season (Table 5.10.16). The distribution of manganese at different sites during pre- and post-monsoon season is shown in Fig. 5.10.12. A concentration of 100 μg/L has been recommended as a desirable limit and 300 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 0.5 mg/L as the provisional guideline value for drinking water (WHO, 1996). It is revealed from the results that about 64% of the samples of the metropolitan city fall within the desirable limit of 100 μg/L and 36% of the samples exceed the desirable limit but within the maximum permissible limit of 300 μg/L during pre-monsoon season (Table 5.10.18).

**Copper (Cu):** The concentration of copper ranges from 3 to 128 μg/L during pre-monsoon season (Table 5.10.15) and 1 to 131 μg/L during post-monsoon season during post-monsoon season (Table 5.10.16). The distribution of copper at different sites during pre- and post-monsoon season is shown in Fig. 5.10.13. The Bureau of Indian Standards has recommended 50 μg/L as the desirable limit and 1500 μg/L as the permissible limit in the absence of alternate source (BIS, 1991). World Health Organization has recommended 2000 μg/L as the provisional guideline value for drinking purpose (WHO, 1996). In the metropolitan city of Kanpur, 96% of the samples fall well within the desirable limit of 50 μg/L for drinking water (Table 5.10.19).

**Chromium (Cr):** The concentration of chromium ranges from 2 to 80 μg/L during pre-monsoon season (Table 5.10.15) and 2 to 14 μg/L during post-monsoon season (Table 5.10.16). The distribution of chromium at different sites during pre- and post-monsoon season is shown in Fig. 5.10.15. A concentration of 50 μg/L has been recommended as a desirable limit for drinking water (BIS, 1991). WHO has also prescribed 50 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kanpur, almost all the samples fall well within the desirable limit for drinking water during both pre- and post-monsoon seasons.

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**Lead (Pb):** In the study area, the concentration of lead ranges from 10 to 38 μg/L during pre-monsoon season (Table 5.10.15) and 8 to 71 μg/L during post-monsoon season (Table 5.10.16). The distribution of lead at different sites during pre- and post-monsoon season is shown in Fig. 5.10.16. The Bureau of Indian Standards has prescribed 50 μg/L lead as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has also prescribed the same guideline value for drinking water (WHO, 1996). In the metropolitan city of Kanpur, all samples fall well within the limit for drinking water during pre-monsoon season.

**Cadmium (Cd):** Cadmium is a nonessential non-beneficial element known to have a high toxic potential. The cadmium content in the study area varies from 3 to 18 μg/L during pre-monsoon season (Table 5.10.15) and 1 to 5 μg/L during post-monsoon season (Table 5.10.16). The distribution of cadmium at different sites during pre- and post-monsoon season is shown in Fig. 5.10.17. The Bureau of Indian Standards has prescribed 10 μg/L cadmium as the desirable limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 3 μg/L cadmium as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kanpur, almost all the samples fall within the permissible limit of 10 μg/L during pre- and post-monsoon seasons (Table 5.10.23).

**Zinc (Zn):** The concentration of zinc in the study area ranges from 48 to 1260 μg/L during pre-monsoon season (Table 5.10.15) and 18 to 1004 μg/L during post-monsoon season (Table 5.10.16). The distribution of zinc at different sites during pre- and post-monsoon season is shown in Fig. 5.10.18. The Bureau of Indian Standards has prescribed 5000 μg/L zinc as the desirable limit and 15000 μg/L as the permissible limit for drinking water (BIS, 1991). WHO has prescribed 3000 μg/L as the guideline value for drinking water (WHO, 1996). In the metropolitan city of Kanpur, all the samples were found within the desirable limit prescribed by BIS (1991) and WHO (1996) during pre- and post-monsoon seasons (Table 5.10.24).

**Arsenic (As):** The concentration of arsenic in the study area ranges from ND to 17 μg/L during pre-monsoon season and ND to 7 during post-monsoon season (Table 5.10.15 & Table 5.10.16). The Bureau of Indian Standards has prescribed 50 μg/L arsenic as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 10 μg/L arsenic as the guideline value for drinking water (WHO, 1996). In the study area, all the samples fall within the permissible limit for drinking water during pre- and post-monsoon seasons.

**Mercury (Hg):** The concentration of mercury in the study area ranges from ND to 2.0 μg/L during pre-monsoon season and is not detected during post-monsoon season (Table 5.10.15 & Table 5.10.16). The Bureau of Indian Standards has prescribed 1 μg/L mercury as the permissible limit for drinking water (BIS, 1991). Beyond this limit, the water becomes toxic. WHO has prescribed 6 μg/L mercury as the guideline value for drinking water (WHO, 2005). In the study area, four samples were found to cross the permissible limit prescribed by BIS (1991) during pre-monsoon season. The mercury contamination in the study area may be attributed to the industrial activities.

It is clearly revealed from the discussion that the presence of heavy metals has been recorded in many samples and the water quality standards have been violated for iron (60% samples), nickel (96% samples) and mercury (16% samples) during pre-monsoon season.

# Pesticides

During the present ground water quality study of the metropolitan city of Kanpur, all the twenty five samples were analysed for organo-chlorinated pesticides (Aldrin, Carbamate, Dieldrine, 2,4-D, DDT, Endosulphan and Methoxychlor) as well as organo-phosphorous pesticides (Anilopyriphos, Chlorpyriphos, Disulfoton, Malathion, Parathion, Phorate, Sulfotep and Thionazin). The results of pesticides analysis for the pre- and post-monsoon season are presented in Table 5.10.27 and 5.10.28. Out of the seven chlorinated pesticides analysed, only three pesticides (Aldrin, DDE and Endosulphan) have been detected at few locations in the ground water of the metropolitan city. However, concentrations of almost all the pesticides were within the permissible limits. The presence of these pesticides in ground water may be attributed due to their use in agricultural activities and for vector control programmes. The pesticide applied on surface might have leached through soil strata under the influence of hydraulic gradient and become source of contamination in ground water. No organo-phosphorous pesticides were detected in any of the ground water samples of the metropolitan city.

# Polynuclear Aromatic Hydrocarbons (PAHs)

Polynuclear aromatic hydrocarons (PAHs) are present in water through air and mainly through industrial discharges. These are shown to be mutagenic and carcinogenic pollutants even at trace level. These are byproducts of petroleum processing or formed as a result of incomplete combustion of organic compounds. Although these are insoluble in water but, sometimes, contaminate water system. The most commonly found PAHs are acenaphthylene, anthracene, dienzo(a,h)anthracene, benzo(a)anthracene, pyrene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene, benzo(ghi)perylene, chrysene, fluorene and phenanthrene. In the metropolitan city of Kanpur, no PAH was detected.

## 5.24.2 Water Quality Evaluation for Irrigation Purpose

The values of sodium percentage (Na%), SAR and RSC in ground water of the metropolitan city of Kanpur are given in Table 5.10.29.

## Salinity

The electrical conductivity values in the metropolitan city of Kanpur varies widely from 698 to 2680 μS/cm during pre-monsoon season and 552 to 2482 μS/cm during post-monsoon season. The ground water with high salinity has limitations in its use for irrigation purpose. Its safe use for irrigation depends upon the texture of the soil and drainage pattern.

## Relative Proportion of Sodium to other Cations

The values of SAR in the ground water of the metropolitan city ranged from 0.22 to 3.15 during pre-monsoon season and 0.23 to 3.10 during post-monsoon season. The sodium percentage in the study area was found to vary from 7.1 to 48.9 during pre-monsoon season and 6.8 to 47.2 during post-monsoon season. All samples of the study area have sodium percentage below the recommended value of 60% for irrigation during pre-monsoon season and such water are suitable for irrigation purpose.

## Residual Sodium Carbonate

During the present study, the RSC values clearly indicate that the ground water of the metropolitan city is free from residual sodium carbonate hazard at all locations.

## Boron

In the present investigation of metropolitan city of Kanpur, the boron content in the ground water clearly indicates that the ground water is safe for irrigation purpose.

## 5.24.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Piper trilinear diagram, Chadha's diagram, Durov diagram, U.S. Salinity Laboratory classification and Gupta's classifications have been used in the present study to classify the ground water of the study area. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 5.10.30 and 5.10.31.

## Piper Trilinear Classification

The chemical analysis data of ground water samples of the metropolitan city of Kanpur have been plotted on trilinear diagram for both the surveys (Fig. 5.10.19 and 5.10.20) and results have been summarized in Table 5.10.30. The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon season.

# Chadha's Diagram

The chemical analysis data of ground water samples of the metropolitan city of Kanpur have been plotted on Chadha' diagram (Fig. 5.10.21 and 5.10.22) and results have been summarized in Table 5.10.30. It is revealed from the results that majority of the samples of the metropolitan city belong to Group 5 (Ca-Mg-$HCO_3$) or Group 6 (Ca-Mg-Cl-$SO_4$) hydrochemical facies in both pre- and post-monsoon seasons.

# Durov's Diagram

The durov plots for the pre- and post-monsoon seasons are shown in Fig. 5.10.23 and 5.10.24 respectively. It is revealed from the results that majority of the samples of the metropolitan city belong to Ca-Mg-$HCO_3$ or Ca-Mg-Cl-$SO_4$ hydrochemical facies in both pre- and post-monsoon seasons.

# U. S. Salinity Laboratory Classification

The chemical analysis data of ground water samples of the metropolitan city of Kanpur has been analysed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 5.10.25 and 5.10.26) and the results have been summarized in Table 5.10.30. It is revealed from the results that the majority of ground water samples of the metropolitan city of Kanpur falls under water types C3-S1 followed by C2-S1. The C3-S1 type water (high salinity and low SAR) cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected.

# Gupta's Classification

The chemical analysis data of ground water samples of the metropolitan city of Kanpur has been processed as per Gupta's classification for the two sets of data and the results have been summarized in Table 5.10.31**.** It is revealed from the results that the majority of ground water samples of the metropolitan city fall under normal to low saline type on the basis of salinity, non-sodic water as per sodicity and non-alkaline to low alkalinity water as per alkalinity classification**.**

# 5.25 Water Quality Evaluation for Allahabad

The ground water samples collected during pre monsoon and post monsoon seasons from

Allahabad city were analyzed for various parameters as per standard procedures. The analytical results of the water quality parameters of the city are given in **Tables – 5.2** to **5.9**, with the average values of pre and post monsoon seasons. The results obtained have been compared with the standard for Drinking Water (IS:10500) as the water is being used mostly for drinking purposes. The specification for drinking water as per the IS are given in **Table – 5.1**.

**TABLE – 5.1**
**IS:10500 DRINKING WATER STANDARD**

***All Values in mg/L unless specified except pH and in Max. except Total Residual Chlorine which is Min.***

| Parameters | **Desirable Limit** | **Permissible Limit** |
|---|---|---|
| Alkalinity | 200 | 600 |
| Aluminium | 0.03 | 0.2 |
| Arsenic | 0.05 | NR |
| Boron | 1.0 | 5 |
| Cadmium | 0.01 | NR |
| Calcium | 75 | 200 |
| Chloride | 250 | 1000 |
| Chromium Hexavalent | 0.05 | NR |
| Colour | 5 | 25 |
| Copper | 0.05 | 1.5 |
| Cyanide | 0.05 | NR |
| Fluoride | 1.0 | 1.5 |
| Hardness | 300 | 600 |
| Iron | 0.3 | 1.0 |
| Lead | 0.05 | NR |
| Magnesium | 30 | 100 |
| Manganese | 0.1 | 0.3 |
| Mercury | 0.001 | NR |
| Nitrate | 45 | 100 |
| Oil & Grease | 0.01 | 0.03 |
| pH | 6.5-8.5 | NR |
| Phenols | 0.001 | 0.002 |
| Selenium | 0.01 | NR |
| Sulphate | 200 | 400 |
| Total Coliform (MPN/100 mL) | 10.0 | NR |
| Total Dissolved Solids | 500 | 2000 |
| Total Residual Chlorine | 0.2 | -- |
| Turbidity (NTU) | 5 | 10 |
| Zinc | 5 | 15 |

**Water Quality Results:**

The analytical results of the water quality monitored during pre and post monsoon period of Allahabad city are given in **Tables – 5.2 to 5.9** which are given as annexure.

**Discussion on Water Quality Monitoring during Pre Monsoon :**

The analysis results indicate the following in different areas :

***Industrial Area***

Only one sample was collected from the Industrial area as Allahabad is basically not an industrial city. The sample was collected from the main Industrial area which is the Naini Industrial Area. The sample was collected from a tube well near market. The pH at this location is almost neutral with a value of 7.3 which is well within the standard limit indicating thereby that the water in this area is suitable for drinking. The Total Dissolved Solids (TDS) are 451 mg/L and the Conductivity is 750 μmhos/cm, which shows the correlation between the two that the conductivity is also high with increase of TDS. The BOD is 0.2 mg/L in the industrial area and COD is 3.0 mg/L, which are negligible. Though there is no standard value prescribed for BOD and COD, the values indicate that the water is not contaminated. The value of Fluoride is 0.63 mg/L which is within the specified limit whereas Hardness is 324 mg/L which is slightly higher than the desirable limit but within the permissible limit. The cations and anions are within limits except Magnesium and Alkalinity which are slightly higher than the prescribed standard and could be mainly due to the nearby industries. The heavy metals in this area are not very high ranging between ND to 0.14 mg/L, indicating the presence of some heavy metals which could be due to the industries in this region. However, the value of Iron which is 1.45 mg/L is higher than the permissible limit. The total and fecal coliforms are also negligible in this sample indicating thereby that there is no bacteriological contamination. Also no pesticides were found in this sample indicating thereby that there are no pesticides in this area.

***Residential Area***

The pH at all the locations in residential area is ranging between 7.2-8.1 which is well within the standard limit indicating thereby that the water in this area is suitable for drinking. The Total Dissolved Solids (TDS) are ranging between 281 to 1372 mg/L and the Conductivity ranges between 475 to 1875 μmhos/cm, which shows that both TDS and Conductivity are slightly on the higher side in the residential area. The BOD ranges from 0.1 to 0.3 mg/L in the residential area and COD ranges from 1.0 to 6.0 mg/L, which though being negligible is slightly higher than the industrial area, indicating thereby that this increase is due to higher organic content in the effluents from residential area. The values of Fluoride are ranging between 0.24 to 1.03 mg/L and Hardness between 180 to 1128 mg/L which are within the specified limits at all the locations, except at Hand Pump near Maya Press where Hardness is the highest with a value of 1128 mg/L. The value of Phosphate is ranging between 0.38 to 0.61 mg/L at all the locations, which is acceptable. The cations and anions are also within limits at all the locations but Sodium and Magnesium are slightly higher in general at some locations ranging between 29.5 to 86 mg/L and 22.0 to 89.6 mg/L, respectively. The higher sodium content could be due to the addition of bleaching powder. The values of Alkalinity are ranging between 228 to 1196 mg/L which is higher than the prescribed standard and could be due to contamination from the residential area. The heavy metals in this area are again not very high ranging between 0.01 to 0.31 mg/L, indicating the presence of some heavy metals. However, Iron is found to be on the higher side at most of the locations, the highest being 6.25 mg/L at the hand pump at Zero Road. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations, except at one or two locations where the MPN values have been found to be between 2.0 and 4.0 MPN/100 mL. Though the desirable standard value is 10.0 MPN/100 mL and these values are within the limit, but it indicates that there is some percolation of sewage water into the ground water which could increase in due course of time. Also no pesticides were found in this area.

***Landfill Area***

Only one sample was collected from the landfill area as the municipal solid waste disposal site of Allahabad city is in Naini. The location of this hand pump is near a petrol pump as well as the landfill area. The pH at this location in the landfill area is 7.4 which is well within the standard limit. The Total Dissolved Solids (TDS) are 530 mg/L and the Conductivity 1198 μmhos/cm, which shows that both TDS and Conductivity are higher in the landfill area. The BOD value is 0.1 mg/L in the landfill area and COD value is 2.0 mg/L, which are quite negligible. The value of Fluoride is 1.25 mg/L and Hardness is 372 mg/L which are slightly higher than the desirable limit but within the permissible limit. The value of Phosphate is 0.42 mg/L at this location, which is acceptable. The cations and anions are also within limits at this location but Magnesium is again slightly higher than the desirable limit but within the permissible limit. The value of Sodium is also slightly higher. The value of Alkalinity is 416 mg/L which is higher than the prescribed standard and could be due to contamination from the landfill area. The heavy metals in this area are again not very high ranging between 0.01 to 0.21 mg/L, indicating the presence of some quantity of heavy metals. The value of Iron is 1.27 mg/L which is again higher than the permissible standard. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at this location, indicating that they are within limits. Also no pesticides were found in this sample indicating thereby that there are no pesticides in this area.

**Discussion on Water Quality Monitoring during Post Monsoon**

Water samples were collected in the month of September after the monsoon to evaluate the changes in water quality. All the sampling stations were same as those for pre monsoon period and the results were also compared with the pre monsoon period. None of the samples indicated the presence of pesticides. The inferences derived are mentioned below.

Industrial Area

The average value of pH, of pre and post monsoon period, at this location is almost neutral of the value of 7.3 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking. The average value of Total Dissolved Solids (TDS) is 435 mg/L and the Conductivity is 736 μmhos/cm, which shows the correlation between the two that the conductivity has been increasing on increase of TDS or decreasing on decrease of TDS. However, the value of TDS is within the desirable limit at this location. The average value of BOD is 0.2 mg/L, which is quite low and COD is 2.5 mg/L, which is also negligible. Though there is no standard value prescribed for BOD and COD, the values indicate that the water is not contaminated. The average value of Fluoride is 0.43 mg/L, the minimum being 0.23 mg/L during the post monsoon period and the maximum being 0.63 mg/L during the pre monsoon period. The average value of Hardness is 310 mg/L, the maximum being 324 mg/L during the pre monsoon period and the minimum being 296 mg/L during the post monsoon period which is within the permissible limit during both the seasons. The average value of Phosphate is 0.3 mg/L which is acceptable. The average values of cations and anions are within limits during the pre and post monsoon periods except Magnesium which is higher than the desirable limit but within the permissible limit during the post monsoon period and the average being 50.8 mg/L The average value of Alkalinity is 338 mg/L which is higher than the desirable limit of the prescribed standard which could be mainly due to the nearby industries, although the value is within the permissible limit. The average values of heavy metals in this area are not very high ranging between 0.01 to 0.07 mg/L, indicating the presence of some heavy metals which could be due to the industries in this region. However, the average value of Iron in this area has been higher than the desirable limit but within the permissible limit. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at this location indicating thereby that there is no bacteriological contamination. Also no pesticides have been encountered in this area.

***Residential Area***

The average value of pH, of pre and post monsoon period, at all the locations in the residential area is almost neutral ranging between 7.1-7.8 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking. The average maximum value 7.8 of pH was observed at hand pump of Mumfordganj and tube well at Civil Lines which is also well within the standard limit. The average values of Total Dissolved Solids (TDS) are ranging between 236 to 1298 mg/L and the Conductivity ranges between 446 to 1844 μmhos/cm, which shows that both TDS and Conductivity are on the higher side at some of the locations in the residential area. The values of TDS are higher than the desirable limit at Keetganj, Bakshi Bandh, Jagram Chauraha, Transport Nagar, Karkaraghat, Zero Road, Mohtsimganj, Modern School, Meerapur and Maya Press but within the permissible limit at all the locations. The highest value of TDS 1372 mg/L was recorded at hand pump, Maya Press during the pre monsoon period and the highest value of Conductivity 1875 μmhos/cm was recorded at hand pump, Mohtsimganj, during the pre monsoon period. The average values of BOD range from 0.1 to 0.3 mg/L, the highest being 0.3 mg/L during pre and post monsoon period at Transport Nagar in the residential area and COD ranges from 1.0 to 5.5 mg/L, the highest being 6.0 mg/L at hand pumps of Keetganj and Phaphamau during the pre monsoon period, which though being negligible are slightly higher than the industrial area, indicating thereby that this increase is due to higher organic content in the effluents from residential area. The average values of Fluoride are ranging between 0.23 to 0.93 mg/L, the maximum being 1.03 mg/L at Keetganj during pre monsoon period and Hardness between 154 to 1092 mg/L, the maximum being 1128 mg/L during the pre monsoon period at Maya Press, which are not within the specified limits at all the locations. The average values of Phosphate are ranging between 0.24 to 0.55 mg/L at all the locations, which is acceptable, though no limit has been specified for phosphate in the IS for drinking water. The average values of cations and anions are within limits at all the locations but Sodium is higher in general at all the locations ranging between 24.0 to 81.55 mg/L, which could be due to the addition of bleaching powder. Also the value of Magnesium is higher than the desirable limit at most of the places. The average values of Alkalinity are ranging between 204 to 918 mg/L, the highest being 1196 mg/L during the pre monsoon period at Maya Press. All the values of Alkalinity are higher than the desirable limit of the prescribed standard which could be due to contamination from the residential area, although these values are within the permissible limit at some places. The average values of Chloride are higher than the desirable limit at Keetganj, Bakshi Bandh, Zero Road, Mohtsimganj, Bairahana, Maya Press and Modern School, but they are within the permissible limit at all the places. The average values of Nitrate are higher than the desirable limit at Bakshi Bandh, Mohtsimganj and Modern School, the highest being 83.75 mg/L at Mohtsimganj during the pre monsoon period, but they are again within the permissible limit at all the places. The average values of Sulphate are well within the desirable limit at all the places in the residential area. The average values of heavy metals in this area are again not very high ranging between 0.01 to 0.23 mg/L, indicating the presence of some heavy metals. However, all the values of heavy metals are below the desirable and permissible limits of the standard. But the average values of Iron are exceeding the permissible limit at almost all the places, the highest being 6.25 mg/L at Zero Road during the pre monsoon period. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations, except at two locations which are Jagram Chauraha and Maya Press where the average MPN value for total coliform have been found to be 3.0 and 1.0 MPN/100 mL, respectively and the highest being 4.0 MPN/100 mL at Jagram Chauraha during the pre monsoon period. Though the desirable standard value is 10.0 MPN/100 mL and these values are within the limit, but it indicates that there is some percolation of sewage water into the ground water which could increase in due course of time. None of the samples showed the presence of Pesticides.

***Landfill Area***

The average value of pH, of pre and post monsoon period, at this location in the landfill area is also almost neutral of the value of 7.4 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking. The average value of Total Dissolved Solids (TDS) is 477 mg/L and the Conductivity is 973 μmhos/cm, which shows that both TDS and Conductivity are slightly higher in the landfill area, but the values of TDS are within the desirable limit of the standard. The average value of BOD is 0.1 mg/L at this location, the value being the same 0.1 mg/L during both pre and post monsoon period in the landfill area and the average value of COD is 1.5 mg/L, which is also quite negligible. The average value of Fluoride is 0.87 mg/L, the maximum being 1.25 mg/L during the pre monsoon period and Hardness is 330 mg/L, the maximum being 372 mg/L during the pre monsoon period, which are within the permissible limit at this location. The average value of Phosphate is 0.30 mg/L, the highest being 0.42 mg/L during the pre monsoon period, which is acceptable, though no limit has been specified for phosphate in the IS for drinking water. The average values of cations and anions are within limits at this location but again Sodium and Magnesium are slightly higher in general. The average value of Alkalinity is 370 mg/L, the highest being 416 mg/L during the pre monsoon period. Both the values of Alkalinity are higher than the desirable limit of the prescribed standard which could be due to contamination from the landfill area, although these values are within the permissible limit. The average values of Chloride, Nitrate and Sulphate are well within the desirable limits of the prescribed standard. The average values of heavy metals in this area are again not very high ranging between 0.01 to 0.11 mg/L, indicating the presence of some quantity of heavy metals. However, all the values of heavy metals are below the desirable and permissible limits of the standard except Iron, the average value of which is 1.02 mg/L, the highest being 1.27 mg/L during the pre monsoon period. This is exceeding the permissible limit as well. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at this location indicating that they are within limits. No pesticides have been found in this area.

Based on the observation and assessment made during pre and post monsoon monitoring of Ground Water Quality of Metro City of Allahabad, the following recommendations are made:

- Variation in water quality was observed during both the periods of the study.
- Ground water quality varies from place to place with the depth of water table which is reflected from the values obtained at same locations with different sources.
- Water source should be thoroughly investigated before recommending it for use, whether it is private or government boring.
- Periodical investigation should be conducted every two to three years on quarterly basis to evaluate the level of ground water contamination in the study area.
- The ground water in the city can be put under hard water category as it is exceeding the prescribed limits of hardness at most of the locations.

- Alternative drinking water source may be provided along the river bank because people residing nearby are using hand pump water for drinking and other domestic purposes.
- Public awareness should be created among the masses particularly for the people residing along the bank of the river Yamuna for consumption of safe drinking water.
- It is suggested that some low cost and easy to implement technique may be provided to the consumers for removing hardness, total dissolved solids and chloride in water where the values exceed the permissible limit.
- With respect to the other physico-chemical properties of the samples collected, it is either conforming to desirable or permissible limits.
- The Iron content was found to be exceeding the permissible limit at most of the locations. One of the reasons could be due to the characteristic of the stratum of the area.
- The concentration of Boron, Chromium and Arsenic were observed as not detectable.
- The samples in respect of concentration of Copper, Lead, Manganese and Zinc were conforming to the desirable limits.
- The Aluminium was found to be within either the permissible limit or desirable limit.
- Bacteriological contamination was observed at one or two locations in the residential area, but it was within the limit of the prescribed standard.
- The quality of ground water from a few shallow hand pumps or tube wells has been impaired in some of the areas. However, the deep bore hand pumps or tube wells have not yet been affected.
- The pollution of ground water in the affected areas with respect to various bacteriological, health related and aesthetic parameters and over dependency on ground water should be viewed seriously.
- The contamination is restricted to certain isolated shallow ground water pockets indicating that it is a localized effect.

## 5.26 Water Quality Evaluation of Varanasi

The ground water samples collected during pre monsoon and post monsoon seasons from Varanasi city were analyzed for various parameters as per standard procedures. The analytical results of the water quality parameters of the city are given in **Tables – 5.2** to **5.9**, with the average values of pre and post monsoon seasons. The results obtained have been compared with the standard for Drinking Water (IS:10500) as the water is being used mostly for drinking purposes. The specification for drinking water as per the IS are given in **Table – 5.1**

**TABLE – 5.1**

**IS:10500 DRINKING WATER STANDARD**

***All Values in mg/L unless specified except pH and in Max. except Total Residual Chlorine which is Min.***

| Parameters | Desirable Limit | Permissible Limit |
|---|---|---|
| Alkalinity | 200 | 600 |
| Aluminium | 0.03 | 0.2 |
| Arsenic | 0.05 | NR |
| Boron | 1.0 | 5 |
| Cadmium | 0.01 | NR |
| Calcium | 75 | 200 |
| Chloride | 250 | 1000 |

| | | |
|---|---|---|
| Chromium Hexavalent | 0.05 | NR |
| Colour | 5 | 25 |
| Copper | 0.05 | 1.5 |
| Cyanide | 0.05 | NR |
| Fluoride | 1.0 | 1.5 |
| Hardness | 300 | 600 |
| Iron | 0.3 | 1.0 |
| Lead | 0.05 | NR |
| Magnesium | 30 | 100 |
| Manganese | 0.1 | 0.3 |
| Mercury | 0.001 | NR |
| Nitrate | 45 | 100 |
| Oil & Grease | 0.01 | 0.03 |
| pH | 6.5-8.5 | NR |
| Phenols | 0.001 | 0.002 |
| Selenium | 0.01 | NR |
| Sulphate | 200 | 400 |
| Total Coliform (MPN/100 mL) | 10.0 | NR |
| Total Dissolved Solids | 500 | 2000 |
| Total Residual Chlorine | 0.2 | -- |
| Turbidity (NTU) | 5 | 10 |
| Zinc | 5 | 15 |

**Discussion on Water Quality Monitoring during Pre Monsoon:**

The analysis results indicate the following in different areas:

***Industrial Area***

The pH at all the locations is almost neutral ranging between 7.5-7.7 which is well within the standard limit indicating thereby that the water in this area is suitable for drinking. The Total Dissolved Solids (TDS) are ranging between 396 to 1682 mg/L and the Conductivity ranges between 116 to 1700 μmhos/cm, which shows the correlation between the two that the conductivity has been increasing on increase of TDS. The BOD ranges from 0.2 to 0.9 mg/L in the industrial area and COD ranges from 2.0 to 3.0 mg/L, which are negligible. Though there is no standard value prescribed for BOD and COD, the values indicate that the water is not contaminated. The values of Fluoride are ranging between 0.59 to 0.97 mg/L which are within the desirable limit and Hardness between 316 to 840 mg/L which are within the permissible limits at all the locations, except at Ram Nagar where Hardness is much higher. The Phosphate is ranging between 0.30 to 1.43 mg/L, which is acceptable. The cations and anions are within limits at all the locations but Sodium is higher in general at all the locations ranging between 23.5 to 88.2 mg/L, which could be due to the addition of bleaching powder. The value of Magnesium is also slightly higher than the desirable limit at one location which is Chandpur. The values of Alkalinity are ranging between 284 to 532 mg/L which are higher than the desirable limit but within the permissible limit and could be mainly due to the nearby industries. The values of Chloride, Nitrate and Sulphate are well within the desirable limit at all the locations. The heavy metals in this area are not very high ranging between ND to 0.31 mg/L, indicating the presence of some heavy metals which could be due to the industries in this region. The values of Iron are ranging between 0.35 to 1.21 mg/L, which are exceeding the desirable limit at all the places, whereas at Ram Nagar it is 1.21 mg/L which is exceeding the permissible limit as well. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations indicating thereby that there is no bacteriological contamination. Also no pesticides were found at all the locations indicating thereby that there are no pesticides in this area.

***Residential Area***

The pH at all the locations in residential area is ranging between 7.3-7.8 which is well within the standard limit indicating thereby that the water in this area is suitable for drinking. The Total Dissolved Solids (TDS) are ranging between 250 to 998 mg/L and the Conductivity ranges between 413 to 3240 μmhos/cm, which shows that both TDS and Conductivity are slightly on the higher side in the residential area at some of the locations. The BOD ranges from 0.1 to 1.0 mg/L in the residential area and COD ranges from 2.0 to 14.0 mg/L, which though being negligible is slightly higher than the industrial area, indicating thereby that this increase is due to higher organic content in the effluents from residential area. The values of Fluoride are ranging between 0.09 to 2.05 mg/L, the highest being at Tube well, Sigra which is 2.05 mg/L and exceeding the permissible limit. The Hardness is ranging between 182 to 871 mg/L which are within the specified limits at all the locations, except at Hand Pump at Ram Katora, Hand Pump at Paharia, Hand Pump at Kamaoli and Tube well near Cant. Railway Station which are exceeding the permissible limit. The value of Phosphate is ranging between 0.24 to 3.30 mg/L at all the locations, which is reasonably acceptable. The cations and anions are also within limits at all the locations but Sodium and Magnesium are slightly higher in general at some locations ranging between 27.0 to 150.8 mg/L and 20.1 to 137.5 mg/L, respectively. The higher sodium content could be due to the addition of bleaching powder. The values of Alkalinity are ranging between 282 to 514 mg/L which is higher than the desirable standard and could be due to contamination from the residential area. The values of Chloride, Nitrate and Sulphate are well within the desirable limits at all the locations. The heavy metals in this area are again not very high ranging between 0.01 to 0.36 mg/L, indicating the presence of some heavy metals. However, Iron is found to be on the higher side at four locations, the highest being 2.14 mg/L at the hand pump at Sonarpura. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations, except at one location where the MPN value has been found to be 4.0 MPN/100 mL. Though the desirable standard value is 10.0 MPN/100 mL and these values are within the limit, but it indicates that there is some percolation of sewage water into the ground water which could increase in due course of time. Also no pesticides were found in this area.

***Landfill Area***

Only one sample was collected from the landfill area as one of the municipal solid waste dumping site of Varanasi city is in Raj Ghat. The pH at this location in the landfill area is 7.4 which is well within the standard limit. The Total Dissolved Solids (TDS) are 452 mg/L and the Conductivity is 1370 μmhos/cm, which shows that both TDS and Conductivity are slightly higher in the landfill area. The BOD value is 0.2 mg/L in the landfill area and COD value is 6.0 mg/L, which are quite negligible. The value of Fluoride is 0.48 mg/L which is well within the desirable limit. The Hardness is 401 mg/L which is slightly higher than the desirable limit but within the permissible limit. The value of Phosphate is 0.38 mg/L at this location, which is acceptable. The cations and anions are also within limits at this location but the value of Sodium is again slightly higher. The value of Alkalinity is 450 mg/L which is higher than the prescribed desirable standard and could be due to contamination from the landfill area. The value of Chloride, Nitrate and Sulphate are again well within the desirable limits. The heavy metals in this area are again not very high ranging between 0.01 to 0.22 mg/L, indicating the presence of some quantity of heavy metals. The value of Iron is 1.0 mg/L which is just within the permissible standard. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at this location, indicating that they are within limits. Also no pesticides were found in this sample indicating thereby that there are no pesticides in this area.

**Discussion on Water Quality Monitoring during Post Monsoon**

Water samples were collected in the month of September after the monsoon to evaluate the changes in water quality. All the sampling stations were same as those for pre monsoon period and the results were also compared with the pre monsoon period. None of the samples indicated the presence of pesticides. The inferences derived are mentioned below :

***Industrial Area***

The average value of pH, of pre and post monsoon period, at all the locations is almost neutral ranging between 7.4-7.6 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking. The maximum average value 7.6 of pH was observed at Tube well at Munduadih which is also well within the standard limit. The average values of Total Dissolved Solids (TDS) are ranging between 339 to 1332.5 mg/L and the Conductivity ranges between 79.5 to 1665 µmhos/cm, which shows the correlation between the two that the conductivity has been increasing on increase of TDS. However, the values of TDS are within the desirable limit at all locations except at Hand Pump at Ram Nagar which are within the permissible limit. The average values of BOD range from 0.2 to 0.75 mg/L, the highest being 0.9 mg/L during pre monsoon period at Ram Nagar in the industrial area and COD ranges from 1.5 to 2.0 mg/L, the highest being 3.0 mg/L at Ram Nagar during pre monsoon period, which are negligible. Though there is no standard value prescribed for BOD and COD, the values indicate that the water is not contaminated. The average values of Fluoride are ranging between 0.44 to 0.95 mg/L, the maximum being 0.97 mg/L at Ram Nagar during pre monsoon period and Hardness between 252 to 787.5 mg/L, the maximum being 840 mg/L during the pre monsoon period at Ram Nagar, which is higher than the permissible limit, but the values at other locations are within the specified limits. The average values of Phosphate are ranging between 0.28 to 0.79 mg/L, which are acceptable. The average values of cations and anions are within limits at all the locations but Sodium is higher in general at all the locations ranging between 22.4 to 81.75 mg/L, which could be due to the addition of bleaching powder. The average values of Alkalinity are ranging between 264 to 405 mg/L which is higher than the desirable limit of the prescribed standard and could be mainly due to the nearby industries, although these values are within the permissible limit. The average values of Chloride, Nitrate and Sulphate are well within the desirable limits at all the locations. The average values of heavy metals in this area are not very high ranging between 0.01 to 0.19 mg/L, indicating the presence of some heavy metals which could be due to the industries in this region. However, the average values of Iron are ranging between 0.3 to 1.0 mg/L which are just within the limit of the prescribed standard. The average values of total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations indicating thereby that there is no bacteriological contamination. Also no pesticides have been encountered in this area.

***Residential Area***

The average value of pH, of pre and post monsoon period, at all the locations in the residential area is almost neutral ranging between 7.3-7.7 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking.

The average maximum value 7.7 of pH was observed at tube well of Sigra which is also well within the standard limit. The average values of Total Dissolved Solids (TDS) are ranging between 227.5 to 869.5 mg/L and the Conductivity ranges between 378 to 3150 μmhos/cm, which shows that both TDS and Conductivity are on the higher side at some of the locations in the residential area. The values of TDS are higher than the desirable limit at Ram Katora, Peeli Kothi, Paharia, Kamaoli and Cantt. Railway Station but within the permissible limit at all the locations. The highest value of TDS 998 mg/L was recorded at hand pump, Paharia during the pre monsoon period and the highest value of Conductivity 3240 μmhos/cm was recorded at hand pump, Kamaoli, during the pre monsoon period. The average values of BOD range from 0.1 to 0.8 mg/L, the highest being 1.0 mg/L during pre monsoon period at hand pumps at Sonarpura and Paharia in the residential area and COD ranges from 1.5 to 10.0 mg/L, the highest being 14.0 mg/L at hand pump of Paharia during the pre monsoon period, which though being negligible is slightly higher than the industrial area, indicating thereby that this increase is due to higher organic and inorganic contents in the effluents from residential area. The average values of Fluoride are ranging between 0.08 to 1.28 mg/L, the maximum being 2.05 mg/L at Sigra during pre monsoon period and Hardness between 153 to 717 mg/L, the maximum being 871 mg/L during the pre monsoon period at Paharia, which are not within the specified permissible limits at two locations. The average values of Phosphate are ranging between 0.20 to 2.19 mg/L at all the locations, which is acceptable, though no limit has been specified for phosphate in the IS for drinking water. The average values of cations and anions are within limits at all the locations but Sodium is higher in general at some of the locations ranging between 25.8 to 144.15 mg/L, which could be due to the addition of bleaching powder. Also the average values of Magnesium are higher than the desirable limit at most of the places but within the permissible limit at all the places. The average values of Calcium and Potassium are well within the desirable limits at all the places. The average values of Alkalinity are ranging between 216.5 to 479 mg/L, the highest being 514 mg/L during the pre monsoon period at hand pump, Paharia. All the average values of Alkalinity are higher than the desirable limit of the prescribed standard which could be due to contamination from the residential area, although these values are within the permissible limit at all the places. The average values of Chloride, Nitrate and Sulphate are well within the desirable limit at all the places in the residential area. The average values of heavy metals in this area are again not very high ranging between 0.01 to 0.20 mg/L, indicating the presence of some heavy metals. However, all the values of heavy metals are below the desirable and permissible limits of the standard. But the average values of Iron are exceeding the permissible limit at three places, the highest being 2.14 mg/L at hand pump, Sonarpura during the pre monsoon period. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at all the locations, except at one location which is hand pump, Sonarpura where the average MPN value for total coliform has been found to be 3.0 MPN/100 mL and the highest being 4.0 MPN/100 mL at Sonarpura during the pre monsoon period. Though the desirable standard value is 10.0 MPN/100 mL and these values are within the limit, but it indicates that there is some percolation of sewage water into the ground water which could increase in due course of time. None of the samples showed the presence of Pesticides.

***Landfill Area***

The average value of pH, of pre and post monsoon period, at this location in the landfill area is also almost neutral of the value of 7.3 which is well within the standard limit for drinking water indicating thereby that the water in this area is suitable for drinking. The average value of Total Dissolved Solids (TDS) is 413.5 mg/L and the Conductivity is 1345 μmhos/cm, which shows that both TDS and Conductivity are slightly higher in the landfill area, but the values of TDS are within the desirable limit of the standard. The average value of BOD is 0.15 mg/L at this location, the value being 0.2 mg/L during pre monsoon period in the landfill area and the average value of COD is 4.5 mg/L, which is also quite negligible. The average value of Fluoride is 0.24 mg/L, the maximum being 0.48 mg/L during the pre monsoon period and Hardness is 337.5 mg/L, the maximum being 401 mg/L during the pre monsoon period, which are within the permissible limit at this location. The average value of Phosphate is 0.30 mg/L, the highest being 0.38 mg/L during the pre monsoon period, which is acceptable, though no limit has been specified for phosphate in the IS for drinking water. The average values of cations and anions are within limits at this location but again Sodium is slightly higher in general. The average value of Alkalinity is 381 mg/L, the highest being 450 mg/L during the pre monsoon period. Both the values of Alkalinity are higher than the desirable limit of the prescribed standard which could be due to contamination from the landfill area, although these values are within the permissible limit. The average values of Chloride, Nitrate and Sulphate are well within the desirable limits of the prescribed standard. The average values of heavy metals in this area are again not very high ranging between 0.01 to 0.12 mg/L, indicating the presence of some quantity of heavy metals. However, all the values of heavy metals are below the desirable and permissible limits of the standard except Iron, the average value of which is 0.7 mg/L, the highest being 1.0 mg/L during the pre monsoon period. This is exceeding the desirable limit but is within the permissible limit. The total and fecal coliforms are also negligible ranging between < 2.0 MPN/100 mL at this location indicating that they are within limits. No pesticides have been found in this area.

Based on the observation and assessment made during pre and post monsoon monitoring of Ground Water Quality of Metro City of Varanasi, the following recommendations are made:

- Variation in water quality was observed during both the periods of the study.
- Ground water quality varies from place to place with the depth of water table.
- Water source should be thoroughly investigated before recommending it for use, whether it is private or government boring.
- Periodical investigation should be conducted every two to three years on quarterly basis to evaluate the level of ground water contamination in the study area.
- Alternative drinking water source may be provided along the river bank because people residing nearby are using hand pump water for drinking and other domestic purposes.
- Public awareness should be created among the masses particularly for the people residing along the bank of the river Ganga for consumption of safe drinking water.
- It is suggested that some low cost and easy to implement technique may be provided to the consumers for removing hardness, total dissolved solids and chloride in water where the values exceed the permissible limit.
- The Alkalinity and Hardness are exceeding the desirable limits at most of the places in Varanasi. It is a natural cause for ground water in tropical alluvial basin. So Varanasi being a city in Ganga basin, these high alkalinity and hardness values are common.
- With respect to the other physico-chemical properties of the samples collected, it is either conforming to desirable or permissible limits.
- The Iron content was found to be exceeding the permissible limit at some of the locations. One of the reasons could be due to the characteristic of the stratum of the area.

- The concentration of Boron, Chromium and Arsenic were observed as not detectable.
- The samples in respect of concentration of Copper, Lead, Manganese and Zinc were conforming to the desirable limits.
- The Aluminium was found to be within either the permissible limit or desirable limit.
- Bacteriological contamination was observed at one location in the residential area, but it was within the limit of the prescribed standard.
- A thorough examination of water supply pipelines should be conducted by Jal Sansthan to check the infiltration of sewage or other kinds of pollutants into pipeline.
- The doses of chlorine should be adjusted in such a way, so as to maintain a minimum concentration of residual chlorine, in the range of 0.2 mg/L at the consumer's end.
- Presently trans Varuna area is facing acute shortage of potable water. Efforts should be made to increase the water supply.
- The steady decline in water level in major part of the district has caused an adverse effect on ecological balance as minor drainage ways that used to have water are now almost dry. This obviously is the result of massive ground water exploitation for irrigation uses. It is imperative to control the declining trend by developing surface water irrigation system. Conjunctive use of surface and ground water should also be adopted. The deeper ground water aquifer system should also be developed.
- The exploration of deeper aquifers should be undertaken between 190 and 700 m bgl in a systematic manner so that as suggested in above point, the development is facilitated.
- The abandoned existing dug wells should be closed up to the land surface to avoid dumping refuge and in turn causing pollution to the ground water.
- Regular monitoring of water level should be practiced.
- The water management practices should be utilized, such as sprinkler irrigation should be encouraged.
- The Central Ground Water Authority should check over exploitation of ground water wherever necessary, with help of State agencies.
- The quality of ground water from a few shallow hand pumps or tube wells has been impaired in some of the areas. However, the deep bore hand pumps or tube wells have not yet been affected.
- The pollution of ground water in the affected areas with respect to various bacteriological, health related and aesthetic parameters and over dependency on ground water should be viewed seriously.
- Efforts should also be made for water harvesting wherever necessary.

## 2.27 Mumbai Groundwater Quality Evaluations

The ground water of the Thane, Mumbai, and Navi Mumbai area has been assessed for its suitability for domestic or any other secondary purposes. Total 46 well water samples and 18 bore well samples were collected in the month of October 03 and were analyzed for different physico chemical parameters, bacteriological, heavy metals pesticides etc

**General Interpretation:** The pH values in the Ground water of Thane, Mumbai and Navi mumbai are confined in the range of 6.8 to 8.26.

**pH Range (Desirable limit:6.5-8.5, Permissible limit:6.5-9.2)**

| Area | Open well | Bore well |
|---|---|---|

| | | |
|---|---|---|
| Thane | 6.8-7.88 | 7.3-7.8 |
| Navi Mumbai | 7.0-8.02 | 7.2-7.8 |
| Mumbai | 7.0-8.0 | 7.2 |

**D.O Range (mg/l)**
Tolerence limit for onland surface waters class A-6min
Tolerence limit for inland surface waters class B-5 min
29 % samples are as per class B.

| Area | Open well | Bore well |
|---|---|---|
| Thane | 2.1-6.0 | 4.0-5.2 |
| Navi Mumbai | 4.0-5.4 | 3.0-5.0 |
| Mumbai | 3.7-5.8 | 3.0 |

**BOD Range (mg/l)**
Tolerence limit for onland surface waters class A-2
Tolerence limit for inland surface waters class B-3
All samples are above the limit.

| Area | Open well | Bore well |
|---|---|---|
| Thane | 4-35 | 6-15 |
| Navi Mumbai | 8-22 | 10-18 |
| Mumbai | 6-20 | 13 |

**TDS Range (mg/l) (Desirable limit: 2000mg/l, Permissible limit: 500mg/l)**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 260-1290 | 360-770 |
| Navi Mumbai | 590-1238 | 610-920 |
| Mumbai | 410-840 | 480 |

Dissolved salts are naturally present in ground water. It mainly consists of inorganic salts such as carbonate, bicarbonates, sulphates, phosphates, nitrates, calcium, magnesium sodium, potassium, iron etc. Organic matter and dissolved gases also contributes to the total content. In the present report values of TDS in the ground water varies from 240mg/l to 1290mg/l. It lies in varied range. Dissolved salts content signifies the mineralization process.

57% of the Total samples are above the Desirable limit 500mg/l. The max permissible limit is 2000mg/l has been suggested for drinking water (BIS1991).

High content of TDS may prove fatal to human health. None of the samples are above the permissible limit i.e. 2000mg/l

**Calcium Range (mg/l) (Desirable limit: 75mg/l)**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 15-97 | 30-92 |
| Navi Mumbai | 62-154 | 65-107 |
| Mumbai | 42-120 | 105 |

45 % of the Total samples are above the Desirable limit i.e. 75mg/l

**Magnesium Range (mg/l) (desirable limit: 30mg/l permissible limit: 100mg/l)**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 7-56 | 14-87 |
| Navi Mumbai | 19-74 | 42-83 |
| Mumbai | 14-44 | 83 |

50 % of the Total samples are above the Desirable limit i.e. 30mg/

**Hardness Range (mg/l) (Permissible limit: 300mg/l)**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 77-428 | 118-398 |
| Navi Mumbai | 214-620 | 315-425 |
| Mumbai | 280-456 | 395 |

36 % of the Total samples are above the Desirable limit i.e. 300mg/l

Calcium and magnesium along with their carbonates, sulphates and chlorides contributes to the hardness of the water. Usually Ca. concentration exceeds the Mg concentration due to its abundance in natural rock .The hard water may lead to kidney problems.

**Chlorides Range (mg/l) (Desirable limit-250mg/l)**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 19-130 | 52-129 |
| Navi Mumbai | 54-225 | 75-135 |
| Mumbai | 43-95 | 135 |

The recommended value for chlorides is 250 mg/l as per the BIS std, 1991.In the following report no value exceeds the limit and all are within the limit. No health effects have been reported due to excess consumption of chlorides.

**Heavy metals:**

Heavy metals have received a great importance in recent years due to its accumulative and toxic character. These are one of the major pollutants and are not biodegradable and are biomagnified. For this water is the main source. Therefore heavy metal analysis has achieved a greater importance. Though some metals are useful to human body but they are toxic at higher concentration. The essential minerals are Cu, CO, Zn, and Fe etc but may prove fatal at higher concentration. Heavy metal may cause mental as well as physiological disorders

**Copper (Cu): (µg/l) Limit 50 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 40-160 | 90-140 |
| Navi Mumbai | 40-160 | 50-140 |
| Mumbai | 80-140 | 90 |

84% of samples are above the limit.

**Lead (Pb): ----(µg/l) limit: 100µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 40-139 | T-250 |
| Navi Mumbai | 90-140 | 70-140 |
| Mumbai | 90-140 | 60 |

31% of samples are above the limit, the concentrations of lead in the study area recorded are very high. Maximum level recorded is 880ug/l at Ganesh Mitra Mandal T.M.C. Depo Thane, which is highly polluted due to oil seepage. The prescribed desired limit for drinking water is 50µg/l. If exceeds the value, water is hazardous. The major source of lead contamination is due to combustion of fossil fuel. Lead is removed fro the atmosphere by rainwater and falls back on to the earth surface and seeps into the ground. Lead enters into the food chain and is transferred from one level to another. Another source of lead is corrosion Pb pipes and solders.

**Zinc (Zn): --(µg/l) Limit 5000 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 4400-14500 | 1900-10000 |
| Navi Mumbai | 4000-16000 | 4200-10000 |
| Mumbai | 4500-12000 | 4000 |

61% samples are above the limit. The concentration of zinc varies from 4000ug/l/l to 16300ug/l .The standard prescribed by BSI for zinc is 5000µg/l and desirable limit of 15000 µg/l. 61% of samples are above limit. Zinc occurs naturally in the rocks. There is possibility of Zn to be present in the ground water. Though Zn being the essential element for body process may prove fatal at higher concentration.

**Iron (Fe): (µg/l) limit 300 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 140-360 | 90-280 |
| Navi Mumbai | 240-380 | T-110 |
| Mumbai | 170-340 | 80 |

The concentration of iron in the ground water of Thane, Mumbai and Navi mumbai ranges from 80 µg/l to 380 µg/l. The std desirable limit prescribed by BIS is 300 µg/l. and 1000 µg/l. as maximum permissible limit.23 % of samples crosses the desirable limit of 300 µg/l.
Well water color appears clear but exposed to air causes precipitation of iron due to oxidation giving rusty color and turbidity to the water. It may promote bacterial activities in pipe and service mains causing foul odor high Fe content causes scaling which cause encrusts pipes. The concentration of iron in natural water is controlled by both physico chemical and microbiological factors. The source of iron in water may be due to weathering of rocks as Fe is present naturally. In ground water iron generally occurs in two oxidation states i.e. $Fe^{++}$ and $Fe^{+++}$ forms.

**Manganese (Mn): -(µg/l) limit 100 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 20-210 | T-90 |
| Navi Mumbai | 40-240 | 2-80 |
| Mumbai | 7-140 | 70 |

Mn is an essential element, which does not occur naturally as a metal but is found in various salts and minerals in combination with Fe. Mn may gain entry into the body due to inhalation, consumption of food through drinking water. BIS and WHO have prescribed drinking water std. The limit suggested for Mn is 500 µg/l as permissible limit. Desirable limit is 100 µg/l. 26% of the Total samples are above the limit

**Chromium (Cr): --(µg/l) limit 50 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 20-68 | T-51 |
| Navi Mumbai | 38-58 | T-50 |
| Mumbai | 22-84 | 0-34 |

23% of the total samples are above the limit**,** The study area shows the max Cr content of 84 µg/lat the Buddha nagar Bhandup. and few are in traces.50 µg/l. has been prescribed as permissible limit for drinking water by BIS 1991 and WHO as well. Cr occurs in two oxidized state $Cr^{+3}$ and $Cr^{+6}$ .$Cr^{+6}$is thermodynamically stable species. $Cr^{+3}$ being kinetically stable bound to naturally occurring solids. However $Cr^{+6}$ is more toxic than $Cr^{+3}$ because of its high rate of adsorption through intestinal tracts. Usually $Cr^{+6}$ is reduced to $Cr^{+3}$ and disposed. The studied area shows the maximum value of 84 µg/l.almost 23% of samples shows the value above the prescribed permissible limit.

**Cadmium (Cd)(µg/l) limit 10 µg/l**

| Area | Open well | Bore well |
|---|---|---|
| Thane | 2.0-21.0 | T-8.00 |
| Navi Mumbai | 8.0-21.0 | T-14.0 |
| Mumbai | 8.0-34.0 | 8 |

Cadmium is one of the toxic metal. Cadmium being toxic and non-essential element achieves the major importance for its presence in the samples. The desirable limit for Cd is 10 µg/l prescribed by BIS. 20% of sample crosses the prescribed limit. The maximum-recorded value for Cd is 34 µg/l. few samples are in traces. If present more than 10 µg/l may cause bronchitis, anemia renal stone etc. Cd enters the environment through different Industrial activities. The leachates may percolate into the ground water that adds to Cd pollution.
Cd is well known carcinogen.

**Pesticides:** Pesticides are being in use since last 2-3 decades it is used frequently used to control insects and pests. Pesticides applied on the crops are removed and comes in surface water and from surface water seeps to ground water polluting it. Pesticide may prove fatal at very low level as well. Out of 6 chlorinated pesticides analyzed only one i.e. Lindane is detected in few samples.

**Bacteriological parameters:**

Limit for drinking purpose MPN 10/100ml, Feacal coli 0/100ml, E-coli 0/100ml.

| Area | Open well | Bore well |
|---|---|---|
| Thane | 33-180 | 140-1800 |
| Navi Mumbai | 80-480 | 34-220 |
| Mumbai | 33-900 | 33 |

The coliform group of bacteria is the principal indicator of suitability of water for domestic, industrial or any other uses. The density of coliform group is the criteria for the degree of contamination and has been the basis for bacteriological water quality standard.
Following standards have been recommended by BIS (1991).

- 95% of water samples should not contain any organisms in 100 ml through out the year.
- No water sample should contain E-coli in 100ml water.
- No water sample should contain more than 10 coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

Here in the following sampling stations it is observed that all the samples show the bacterial contamination, this proves that the water from the open as well as bore well is unfit for drinking and is heavily contaminated. The presence of faecal coliforms in ground water indicates a potential public health problem, as it is a source of pathogenic bacteria and viruses. The ground water contamination may be due to percolation of water from domestic sewage and poor sanitation conditions into the aquifers.

In the following para, it is observed that according to BIS (1991), the water is totally unfit for human consumption. Earlier sets samples collected during the period of March 03 to Sept 03 it was observed that the water quality parameters shows that increased level than the recommended. When this data is compared with data of post monsoon collected in march - 04.It was observed that the samples which were collected during period of march-03 to may-03have shown the dilution effect. All pollution parameters show decreased value. The samples that were collected in period of June-03 to sept-03 had showed the concentration effect.i.e. As far as Physicochemical data is concerned it is observed that the samples are indicating high levels of DO, BOD values which are pollution indicating parameter when compared with limits of class A and Class B for inland surface water.

Mostly all wells are bacteriological polluted. This may be because of improper maintenance and unuseness of water from wells. In TMC area well water is only used for domestic purposes other than drinking only during scarcity of water supply. Hence because of stagnancy well water becomes more rancid, due to unavailability of fresh water most of the wells get polluted and were not suitable for drinking purposes. As Thane and its adjoining area being in coastal belt, Chlorides, Sulphates Total hardness and TDS values are more. As far as heavy metals are concerned following observations are noticed.

| Parameter | Limit | Remark |
|---|---|---|
| Pb | 100µg/l | 31%are above limit |
| Cr | 50 µg/l | 23% are above limit |
| Cd | 10 µg/l | 20% are above limit |

In TMC because of unuseness of well water most wells being used as dumping place for domestic waste. High content of heavy metal is because of lot of domestic waste is dumped in well. Domestic waste mainly contains of Nirmalaya, photos, waste batteries, rubber tyres, colored plastic waste, paint boxes and tins etc. that may contribute to high content of heavy metal. Some wells, which are present in Industrial area having cracks around the concrete bricked walls, are showing high content of heavy metals due to seepages. In survey for domestic waste in TMC area had shown high content of heavy metals.

Pesticide analysis carried out for the 1st set of samples and 2nd set for organochlorine and organophosphate pesticides. In first set due to monsoon season all sample shows absence of pesticides. In 2nd set it is observed that 99% samples shows the absence of pesticide content and for others the values are very low than the desirable limit. As Thane and its adjoining area being urban place there is no agricultural activity hence pesticide content is not obtained in well water.

Bacteriological:In TMC area 99% wells are polluted. In first Set of result following wells are with in the prescribed bacteriological limit. PCC/W/9Azad nagar near shiv sena shakha
PCC/W/44 Baburao patil chawl.hanuman nagar Bhandup(w). But in post monsoon period it is observed that well water is contaminated. This is because of mainly large gutter flowing near the well; well wall is made up of bricks only. Plastering was not observed around it.

# 6.0 RECOMMENDATIONS

1. All the ground water extraction structures should be registered and regulated to avoid over exploitation and deterioration of ground water quality.
2. The water obtained from the ground water structures should be tested and analysed to ensure the suitability of ground water for human consumption.
3. The ground water abstraction sources and their surroundings should be properly maintained to ensure hygienic conditions and no sewage or polluted water should be allowed to percolate directly to ground water aquifer.
4. Proper cement platforms should be constructed surrounding the ground water abstraction sources to avoid direct well head pollution.
5. The surrounding surface area of the ground water abstraction structures should be frequently chlorinated by use of bleaching power.
6. Possibilities of construction of artificial recharge structures should be explored to augment the ground water recharge.
7. The hand pumps, which have been identified as having suspected water quality should be painted red to indicate and warn the public that the water drawn from the source is not fit for human consumption.
8. In the absence of alternate safe source of water, the water with excessive undesirable constituents must be treated with specific treatment process before its use for human consumption.
9. The defluoridation treatment option (activated alumin or Nalgonda technique, domestic level) should be undertaken in ground water drawn from sources exceeding the permissible limit of 1.5 mg/L.
10. Treatment option for nitrate should be undertaken in ground water drawn from sources exceeding the permissible limit of 100 mg/L.
11. The ground water drawn from hand pumps should be properly chlorinated to eradicate the presence of bacterial contamination.
12. The untreated sewage and sewerage flowing in various open drains are one of the causes of ground water quality deterioration. Proper under ground sewage system must be laid in all inhabited areas and the untreated sewage and industrial wastes should not be allowed to flow in open drains.
13. A proper system of collection and transportation of domestic waste should be developed. Land fill site(s) should be identified and it must be scientifically designed. Ground water quality near land fill sites should be regularly monitored.
14. The mass awareness should be generated about quality of water, its effect on human health and responsibilities of public to safeguard water resources.

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| **Monitoring planning, data processing, interpretation and report writing** | **Dr. C. K. Chaubey and Dr. C. K. Jain** |
| **Analytical monitoring and Ground water sample analysis** | **Dr. C. K. Chaubey<br>Dr. K. K. S. Bhatia<br>Dr. C. K. Jain<br>Dr. Imran Ali<br>Dr. M. K. Sharma<br>Km. Deepali<br>Km. Rashmi Yadav<br>Km. Krishna Gupta<br>Smt. Babita Sharma<br>Smt. Beena Prashad<br>Sri. Rakesh Goyal** |
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| 2. | Mrs. M. M. Pradhan | Planner & Co ordinator |
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